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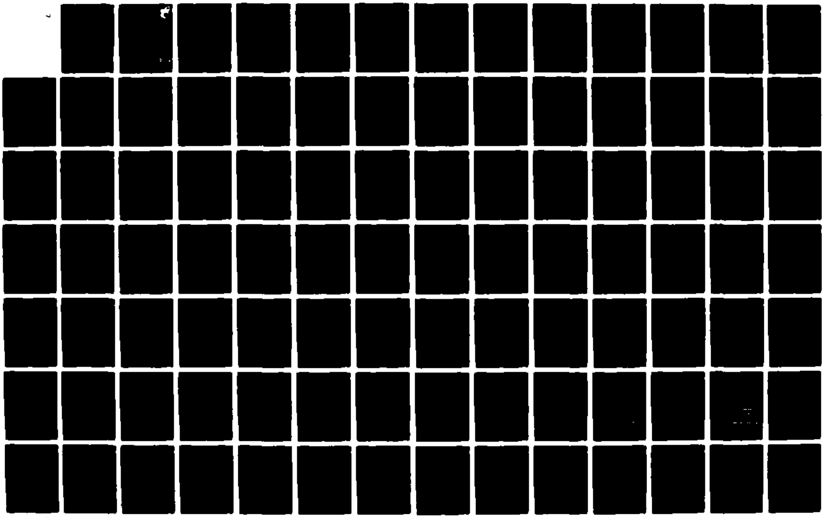

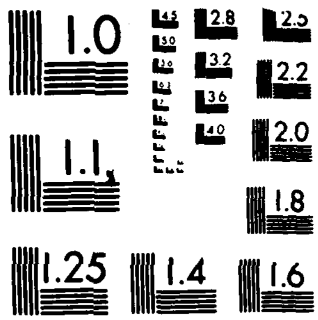

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AFWAL-TR-84-2015
Volume II

USAF MOBILE POWER AND FACILITY ELECTRICITY POWER SYSTEMS ANALYSIS

VOLUME II - APPENDICES

APPLIED CONCEPTS CORPORATION
109K NORTH MAIN STREET
WOODSTOCK, VIRGINIA 22664

MARCH 1984

FINAL REPORT FOR PERIOD JANUARY 1982 - SEPTEMBER 1983

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AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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This technical report has been reviewed and is approved for publication.

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10	01		
10	02		

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

This research built upon previous work which developed a data base for advanced terrestrial energy systems (ATES), and a computerized methodology for multiple criteria decision making (MCDM). Research determined the electric power (MEP) and facilities energy generating system (FEGS) needs. Advanced technologies have little potential to enhance FEGS operational effectiveness, but offer cost savings, especially for remote site and self sufficiency missions. MEP mission support can be enhanced by free piston systems in small sizes, by kinematic stirling and phosphoric acid fuel cells in mid sized applications (flightline, communications support) and by regenerative gas turbines in large systems. R&D programs are recommended to achieve the enhanced operational and cost potential.

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Appendix A

Parametric Data

FOREWORD

Data indicated as "original" are taken from the ATES. Data indicated as "changed" are as provided by technical subcontractors. The following abbreviations are used throughout:

RO = Regenerative Open Cycle
CC = Closed Cycle
NR = Non-Regenerative
TC = Turbo-Compounded
TD = Turbo-Charged
AD = Adiabatic
FP = Free Piston
KS = Kinematic Stirling
PA = Phosphoric Acid
SP = Solid Polymer
PV = Flat Plate
AC = Actively Cooled
EC = Photoelectrochemical
WT = Vertical & Horizontal Wind Turbines

Unless specified no changes were made from data in the ATES.

DESCRIPTION OF PERFORMANCE PARAMETERS FOR MOBILE ELECTRIC POWER SYSTEMS

A. Size. The system envelope in dimensions of length, width and height.

B. Weight. The weight of the system without fuel, coolant, lubricant, electrolyte, and optional equipment.

C. Other Mobility Factors. A qualitative assessment of the degree of mobility based on system transportability by truck or aircraft, system assembly and dismantling time, and need for prior site preparation. (Not considering size or weight per se.)

D. Fuel Type. Primary and emergency fuels which can be used without system adjustment or modification.

E. Fuel Consumption. Rate of fuel consumption, in quantity per hour.

F. Useful Life. The total expected lifetime of the system, either in use (number of hours of operation) or storage (number of years depot storage life).

G. MTBF. Power system availability for operational use in mean time between failure, in hours.

H. Level of Repair. Unit, Intermediate, or Depot Level.

I. Time to Repair. The amount of time required to repair a malfunctioning system.

J. MTBO. Mean time between overhaul.

K. Noise. The loudness and pitch of noise emitted from an operating system under normal load.

L. IR Signature. The level of infra-red radiation emitted from an operating system.

M. EMI. The level of radio frequency electromagnetic radiation emitted from an operating system.

N. Environmental Constraints. Ability to perform under extremes of temperature, humidity, altitude, weather, etc.

O. Operability. Technical training requirements for system operation and maintenance.

P. Start-up Time/Shut-down Time. Elapsed time required to bring the system to full output from a "cold start" condition. Elapsed time to bring the system from full output to an off or standby mode.

Q. Quality of Elec. Output. Variability in output parameters.

Parameter: Lifetime Units: Years

POL kW	Year	RO Orig	RO Chng	CC Orig	CC Chng	NR Orig	NR Chng	TC Orig	TC Chng	TD Orig	TD Chng	AD Orig	AD Chng	FP Orig	FP Chng	KS Orig	KS Chng	PA Orig	PA Chng	SP Orig	SP Chng	PV	AC	EC	WT
5	1985	NCA		NCA		NCA		20		20		NCA		20	NCA	20	3	5	10	NCA		20	20	NCA	20
	1990	NCA		NCA		NCA		20		20		20		20	12	20	6	5	10	5	NCA	20	20	20	20
	2000	NCA		NCA		NCA		20		20		20		20	20	20		5	10	5	10	20	20	20	20
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	1990	20	NCA	NCA		20	11	20		20		20		20	NCA	20	6	5	10	5	NCA	20	20	20	20
	2000	20	NCA	NCA		20	11	20		20		20		20	NCA	20		5	10	5	NCA	20	20	20	20
100	1985	20	NCA	NCA		20	11	20		20		NCA		20	NCA	20	NCA	5	10	NCA		20	20	NCA	20
	1990	20	11	NCA		20	11	20		20		20		20	NCA	20	6	5	10	5	NCA	20	20	20	20
	2000	20	11	NCA		20	11	20		20		20		20	NCA	20		5	10	5	NCA	20	20	20	20
250	1985	20	NCA	20		20	11	20		20		NCA		20	NCA	20	NCA	5	10	NCA		20	20	NCA	20
	1990	20	11	20		20	11	20		20		20		20	NCA	20	NCA	5	10	5	NCA	20	20	20	20
	2000	20	11	20		20	11	20		20		20		20	NCA	20		5	10	5	NCA	20	20	20	20
750	1985	20	NCA	20		20	11	20		20		NCA		20	NCA	20	NCA	5	10	NCA		20	20	NCA	20
	1990	20	11	20		20	11	20		20		20		20	NCA	20	NCA	5	10	5	NCA	20	20	20	20
	2000	20	11	20		20	11	20		20		20		20	NCA	20		5	10	5	NCA	20	20	20	20
5000	1985	20	11	20	11	20	11	20		20		NCA		NCA		NCA		5	10	NCA		20	20	NCA	20
	1990	20	11	20	11	20	11	20		20		20		NCA		NCA		5	10	5	NCA	20	20	20	20
	2000	20	11	20	11	20	11	30		20		20		NCA		NCA		5	10	5	NCA	20	20	20	20

Parameter: Reliability Units: Ordinal; 1-5

FOL KW	Year	RO Orig	RO Chng	CC Orig	CC Chng	NR Orig	NR Chng	TC Orig	TC Chng	TD Orig	TD Chng	AD Orig	AD Chng	FP Orig	FP Chng	KS Orig	KS Chng	PA Orig	PA Chng	SP Orig	SP Chng	PV	AC	EC	WT
5	1985	NCA		NCA		NCA		NCA		3	4	NCA		NCA		NCA		2	3	NCA		3	3	NCA	2
	1990	NCA		NCA		NCA		NCA		3	4	NCA		4	5	4		2	3	NCA		3	3	NCA	2
	2000	NCA		NCA		NCA		NCA		3	4	NCA		4	5	4		2	3	2	3	3	3	3	2
50	1995	NCA		NCA		NCA	3	NCA		3	4	NCA		NCA		NCA		2	3	NCA		3	3	NCA	2
	1990	NCA		NCA		NCA	4	NCA		3	4	NCA		NCA		4		2	3	NCA		3	3	NCA	2
	2000	NCA		NCA		3	5	NCA		3	4	NCA		NCA		4		2	3	NCA		3	3	NCA	2
100	1985	NCA		NCA		NCA	3	3		3	4	NCA		NCA		NCA		2	3	NCA		3	3	NCA	2
	1990	3		NCA		3	4	3		3	4	NCA		NCA		4		2	3	NCA		3	3	NCA	2
	2000	3	4	NCA		3	5	3		3	4	NCA		NCA		4		2	3	NCA		3	3	NCA	2
250	1995	NCA		NCA		3	3	3		3	4	NCA		NCA		NCA		NCA	3	NCA		3	3	NCA	2
	1990	3		NCA		3	4	3		3	4	3		NCA		4	NCA	2	3	NCA		3	3	NCA	2
	2000	3	4	NCA		3	5	3		3	4	3		NCA		4		2	3	NCA		3	3	NCA	2
750	1985	NCA		NCA		3	3	3		3	4	NCA		NCA		NCA		NCA	3	NCA		3	NCA	NCA	2
	1990	3		NCA		3	4	3		3	4	3		NCA		NCA		2	3	NCA		3	3	NCA	2
	2000	3	4	NCA		3	5	3		3	4	3		NCA		4		2	3	NCA		3	3	NCA	2
5000	1985	3		3		3		3		3		NCA		NCA		NCA		NCA	3	NCA		NCA	NCA	NCA	NCA
	1990	3	4	3	4	3	4	3		3		3		NCA		NCA		2	3	NCA		NCA	NCA	NCA	NCA
	2000	3	5	3	5	3	5	3		3		3		NCA		NCA		2	3	NCA		3	NCA	NCA	NCA

1 - high potential unreliability
2 - moderate potential unreliability
3 - average potential unreliability
4 - moderate reliability
5 - high reliability

Parameter: Operational Constraints Units: Ordinal; 1-5

POL kW	Year	RO Orig	RO Chng	CC Orig	CC Chng	NR Orig	NR Chng	TC Orig	TC Chng	TD Orig	TD Chng	AD Orig	AD Chng	FP Orig	FP Chng	KS Orig	KS Chng	PA Orig	PA Chng	SP Orig	SP Chng	PV	AC	EC	WT
5	1985	NCA		NCA		NCA		4		4		NCA		NCA		NCA		3	4	NCA		2	2	NCA	2
	1990	NCA		NCA		NCA		4		4		4		5		5		3	4	3	NCA	2	2	2	2
	2000	NCA		NCA		NCA		4		4		4		5		5		3	4	3	4	2	2	2	2
60	1985	4	2	NCA		4	3	4		4		NCA		NCA		NCA		3	4	NCA		2	2	NCA	2
	1990	4	2	NCA		4	2	4		4		4		5		5		3	4	3	NCA	2	2	2	2
	2000	4	2	NCA		4	2	4		4		4		5		5		3	4	3	NCA	2	2	2	2
100	1985	4	2	NCA		4	3	4		4		NCA		NCA		NCA		3	4	NCA		2	2	NCA	2
	1990	4	2	NCA		4	3	4		4		4		NCA		5		3	4	3	NCA	2	2	2	2
	2000	4	2	NCA		4	3	4		4		4		NCA		5		3	4	3	NCA	2	2	2	2
250	1985	4	NCA	4	NCA	4	NCA	4		4		NCA		NCA		NCA		3	4	NCA		2	2	NCA	2
	1990	4	2	4	NCA	4	3	4		4		4		NCA		5		3	4	3	NCA	2	2	2	2
	2000	4	2	4	NCA	4	3	4		4		4		NCA		5		3	4	3	NCA	2	2	2	2
750	1985	4	NCA	4	NCA	4	3	4		4		NCA		NCA		NCA		3	4	NCA		2	2	NCA	2
	1990	4	2	4	NCA	4	3	4		4		4		NCA		5	NCA	3	4	3	NCA	2	2	2	2
	200	4	2	4	NCA	4	3	4		4		4		NCA		5		3	4	3	NCA	2	2	2	2
5000	1985	4	2	4		4	3	4		4		NCA		NCA		NCA		3	4	NCA		2	2	NCA	2
	1990	4	2	4		4	3	4		4		4		NCA		NCA		3	4	3	NCA	2	2	2	2
	2000	4	2	4		4	3	4		4		4		NCA		NCA		3	4	3	NCA	2	2	2	2

1 - no turn down capability
2 - turn down capability - high efficiency penalty
3 - average turn down capability - average efficiency penalty
4 - moderage turn down capability - moderate efficiency penalty
5 - excellent turn down capability - minor efficiency penalty

Parameter: Type Units: Mobile (M)/Transportation (T)/Fixed (F)

POL kW	Year	RO Orig	RO Chng	CC Orig	CC Chng	NR Orig	NR Chng	TC Orig	TC Chng	TD Orig	TD Chng	AD Orig	AD Chng	FP Orig	FP Chng	KS Orig	KS Chng	PA Orig	PA Chng	SP Orig	SP Chng	PV	AC	EC	WT
5	1985	NCA		NCA		NCA		NCA		M		NCA		NCA		NCA	M	M		NCA		F	F	NCA	F
	1990	NCA		NCA		NCA		NCA		M		NCA		M		M		M		NCA		F	F	NCA	F
	2000	NCA		NCA		NCA		NCA		M		NCA		M		M		M		M		F	F	F	F
60	1985	NCA		NCA		NCA	M	NCA		M		NCA		NCA		NCA		M		NCA		F	F	NCA	F
	1990	NCA		NCA		NCA	M	NCA		M		NCA		NCA		M		M		NCA		F	F	NCA	F
	2000	NCA		NCA		M		NCA		M		NCA		NCA		M		M		NCA		F	F	NCA	F
100	1985	NCA		NCA		NCA	M	M		M		NCA		NCA		NCA		T		NCA		F	F	NCA	F
	1990	M		NCA		M		M		M		NCA		NCA		M		T		NCA		F	F	NCA	F
	2000	M		NCA		M		M		M		NCA		NCA		M		T		NCA		F	F	NCA	F
250	1985	NCA		NCA		NCA		M		M		NCA		NCA		NCA		NCA	T	NCA		F	F	NCA	F
	1990	M		NCA		M		M		M		M		NCA		T	NCA	T		NCA		F	F	NCA	F
	2000	M		NCA		M		M		M		M		NCA		M		T		NCA		F	F	NCA	F
750	1985	NCA		NCA		M		M		M		NCA		NCA		NCA		NCA	F	NCA		NCA	NCA	NCA	F
	1990	T		NCA		M		M		M		M		NCA		NCA		F		NCA		F	F	NCA	F
	2000	T		NCA		M		M		M		M		NCA		T		F		NCA		F	F	NCA	F
5000	1985	T		T		T		T		T		NCA		NCA		NCA		NCA	F	NCA		NCA	NCA	NCA	NCA
	1990	T		T		T		T		T		T		NCA		NCA		F		NCA		NCA	NCA	NCA	NCA
	2000	T		T		T		T		T		T		NCA		NCA		F		NCA		F	NCA	NCA	NCA

Parameter: Operation and Maintenance Units: Ordinal; 1-5

POL kW	Year	RO Orig	RO Chng	CC Orig	CC Chng	NR Orig	NR Chng	TC Orig	TC Chng	TD Orig	TD Chng	AD Orig	AD Chng	FP Orig	FP Chng	KS Orig	KS Chng	PA Orig	PA Chng	SP Orig	SP Chng	PV	AC	EC	WT
5	1985	NCA		NCA		NCA		3		5		NCA		5	NCA	5	4	1		NCA		5	5	NCA	5
	1990	NCA		NCA		NCA		3		5		5		5	1	5	4	1		1	NCA	5	5	5	5
	2000	NCA		NCA		NCA		3		5		5		5	1	5	4	1		1		5	5	5	5
60	1985	3		NCA		3		3		5		NCA		5	NCA	5	NCA	1		NCA		5	5	NCA	5
	1990	3		NCA		3		3		5		5		5	NCA	5	4	1		1	NCA	5	5	5	5
	2000	3		NCA		3		3		5		5		5	NCA	5	4	1		1		5	5	5	5
100	1985	3		NCA		3		3		5		NCA		5	NCA	5	NCA	1		NCA		5	5	NCA	5
	1990	3		NCA		3		3		5		5		5	NCA	5	4	1		1	NCA	5	5	5	5
	2000	3		NCA		3		3		5		5		5	NCA	5	4	1		1		5	5	5	5
250	1985	3	NCA	NCA		3		3		5		NCA		5	NCA	5	NCA	1		NCA		3	3	NCA	3
	1990	3		NCA		3		3		5		5		5	NCA	5	NCA	1		1	NCA	3	3	3	3
	2000	3		NCA		3		3		5		5		5	NCA	5	4	1	NCA	1		3	3	3	3
750	1985	3		3		3		3		5		NCA		5	NCA	5	NCA	1		NCA		3	3	NCA	3
	1990	3		3		3		3		5		5		5	NCA	5	NCA	1		1	NCA	3	3	3	3
	2000	3		3		3		3		5		5		5	NCA	5	4	1		1		3	3	3	3
5000	1985	3		3		3		3		5		NCA		NCA		NCA		1		NCA		3	3	NCA	3
	1990	3		3		3		3		5		5		NCA		NCA		1		1	NCA	3	3	3	3
	2000	3		3		3		3		5		5		NCA		NCA		1		1		3	3	3	3

1 - no apparent, unique technical capabilities required
3 - potential requirement for high skilled technical personnel
5 - definite requirement for high skilled technical personnel

Parameter: Environmental Constraints Units: Ordinal; 1-5

POL kW	Year	RD Orig	RD Chng	CC Orig	CC Chng	NR Orig	NR Chng	TC Orig	TC Chng	TD Orig	TD Chng	AD Orig	AD Chng	FP Orig	FP Chng	KS Orig	KS Chng	PA Orig	PA Chng	SP Orig	SP Chng	PV	AC	EC	WT
5	1985	NCA		NCA		NCA		NCA		4		NCA		NCA		NCA	5	5		NCA		5	5	NCA	5
	1990	NCA		NCA		NCA		NCA		4		NCA		5		5		5		NCA		5	5	NCA	5
	2000	NCA		NCA		NCA		NCA		4		NCA		5		5		5		5		5	5	5	5
60	1985	NCA		NCA		NCA	3	NCA		4		NCA		NCA		NCA		5		NCA		5	5	NCA	5
	1990	NCA		NCA		NCA	4	NCA		4		NCA		NCA		5		5		NCA		5	5	NCA	5
	2000	NCA		NCA		4	5	NCA		4		NCA		NCA		5		5		NCA		5	5	NCA	5
100	1985	NCA		NCA		NCA	3	4		4		NCA		NCA		NCA		5		NCA		5	5	NCA	5
	1990	4		NCA		4		4		4		NCA		NCA		5		5		NCA		5	5	NCA	5
	2000	4	5	NCA		4	5	4		4		NCA		NCA		5		5		NCA		5	5	NCA	5
250	1985	NCA		NCA		NCA	3	4		4		NCA		NCA		NCA		NCA	5	NCA		5	5	NCA	5
	1990	4		NCA		4		4		4		4		NCA		5	NCA	5		NCA		5	5	NCA	5
	2000	4	5	NCA		4	5	4		4		4		NCA		5		5		NCA		5	5	NCA	5
750	1985	NCA		NCA		4	3	4		4		NCA		NCA		NCA		NCA	5	NCA		NCA	NCA	NCA	5
	1990	4		NCA		4		4		4		4		NCA		NCA		5		NCA		5	5	NCA	5
	2000	4	5	NCA		4	5	4		4		4		NCA		5		5		NCA		5	5	NCA	5
5000	1985	4	3	4		4	3	4		4		NCA		NCA		NCA		NCA	5	NCA		NCA	NCA	NCA	NCA
	1990	4		4		4		4		4		4		NCA		NCA		5		NCA		NCA	NCA	NCA	NCA
	2000	4	5	4	5	4	5	4		4		4		NCA		NCA		5		NCA		5	NCA	NCA	NCA

1 - extreme potential environmental constraint
2 - high potential environmental constraint
3 - average potential environmental constraint
4 - moderate potential environmental constraint
5 - minimum potential environmental constraint

Parameter: Location Constraints Units: Ordinal; 1-5

POL kW	Year	RO Orig	RO Chng	CC Orig	CC Chng	NR Orig	NR Chng	TC Orig	TC Chng	TD Orig	TD Chng	AD Orig	AD Chng	FP Orig	FP Chng	KS Orig	KS Chng	PA Orig	PA Chng	SP Orig	SP Chng	PV	AC	EC	WT
5	1985	NCA		NCA		NCA		NCA		3	4	NCA		NCA		NCA	4	4		NCA		3	3	NCA	3
	1990	NCA		NCA		NCA		NCA		3	4	NCA		4	5	4		4		NCA		3	3	NCA	3
	2000	NCA		NCA		NCA		NCA		3	4	NCA		4	5	4		4		4		3	3	3	3
60	1985	NCA		NCA		NCA	3	NCA		3	4	NCA		NCA		NCA		4		NCA		3	3	NCA	3
	1990	NCA		NCA		NCA	3	NCA		3	4	NCA		NCA		4		4		NCA		3	3	NCA	3
	2000	NCA		NCA		3		NCA		3	4	NCA		NCA		4		4		NCA		3	3	NCA	3
100	1985	NCA		NCA		NCA	3	3	4	3	4	NCA		NCA		NCA		4		NCA		3	3	NCA	3
	1990	3		NCA		3		3	4	3	4	NCA		NCA		4		4		NCA		3	3	NCA	3
	2000	3		NCA		3		3	4	3	4	NCA		NCA		4		4		NCA		3	3	NCA	3
250	1985	NCA		NCA		NCA	3	3	4	3	4	NCA		NCA		NCA		NCA	4	NCA		3	3	NCA	3
	1990	3		NCA		3		3	4	3	4	3	4	NCA		4		4		NCA		3	3	NCA	3
	2000	3		NCA		3		3	4	3	4	3	4	NCA		4		4		NCA		3	3	NCA	3
750	1985	NCA		NCA		3		3	4	3	4	NCA		NCA		NCA		NCA	4	NCA		NCA	NCA	NCA	3
	1990	3		NCA		3		3	4	3	4	3	4	NCA		NCA		4		NCA		3	3	NCA	3
	2000	3		NCA		3		3	4	3	4	3	4	NCA		4		4		NCA		3	3	NCA	3
5000	1985	3		3		3		3		3		NCA		NCA		NCA		NCA	4	NCA		NCA	NCA	NCA	NCA
	1990	3		3		3		3		3		3		NCA		NCA		4		NCA		NCA	NCA	NCA	NCA
	2000	3		3		3		3		3		3		NCA		NCA		4		NCA		3	NCA	NCA	NCA

1 - extreme potential locational constraint
2 - high potential locational constraint
3 - average potential locational constraint
4 - moderate potential locational constraint
5 - minimum potential locational constraint

Parameter: Thermal Energy

POL kW	Year	RO Orig	RO Chng	CC Orig	CC Chng	NR Orig	NR Chng	TC Orig	TC Chng	TD Orig	TD Chng	AD Orig	AD Chng	FP Orig	FP Chng	KS Orig	KS Chng	PA Orig	PA Chng	SP Orig	SP Chng	PV	AC	EC	WT
5	1985	NCA		NCA		NCA		NCA		3		NCA		NCA		4		3		NCA		NCA	NCA	NCA	1
	1990	NCA		NCA		NCA		NCA		3		NCA		4		4		3		NCA		NCA	NCA	NCA	1
	2000	NCA		NCA		NCA		NCA		3		NCA		4		4		3		1		NCA	NCA	NCA	1
60	1985	NCA		NCA		5		NCA		3		NCA		NCA		NCA		3		NCA		1	NCA	NCA	1
	1990	NCA		NCA		5		NCA		3		NCA		NCA		2		3		NCA		1	NCA	NCA	1
	2000	NCA		NCA		5		NCA		3		NCA		NCA		2		3		NCA		1	NCA	NCA	1
100	1985	NCA		NCA		5		2		3		NCA		NCA		NCA		3		NCA		1	3	NCA	1
	1990	3		NCA		5		2		3		NCA		NCA		2		3		NCA		1	3	NCA	1
	2000	3		NCA		5		2		4		NCA		NCA		2		3		NCA		1	3	NCA	1
250	1985	NCA		NCA		5		2		3		NCA		NCA		NCA		3		NCA		1	3	NCA	1
	1990	3		NCA		5		2		3		4		NCA		NCA		3		NCA		1	3	NCA	1
	2000	3		NCA		5		2		3		4		NCA		2		3		NCA		1	3	NCA	1
750	1985	NCA		NCA		5		2		3		NCA		NCA		NCA		3		NCA		NCA	NCA	NCA	1
	1990	3		NCA		5		2		3		4		NCA		NCA		3		NCA		1	NCA	NCA	1
	2000	3		NCA		5		2		3		4		NCA		2		3		NCA		1	NCA	NCA	1
5000	1985	3		2		5		2		3		NCA		NCA		NCA		3		NCA		NCA	NCA	NCA	NCA
	1990	3		2		5		2		3		4		NCA		NCA		3		NCA		NCA	NCA	NCA	NCA
	2000	3		2		5		2		3		4		NCA		NCA		3		NCA		1	NCA	NCA	NCA

1 - no potential for heat recovery
2 - minor potential for heat recovery - extremely use limited
3 - potential for heat recovery - use limited
4 - moderate potential for heat recovery - minor use limitation
5 - very high potential for heat recovery

Parameter: Weight Units: Pounds

PGL kW	Year	RD Orig	RD Chng	CC Orig	CC Chng	MR Orig	MR Chng	TC Orig	TC Chng	TD Orig	TD Chng	AD Orig	AD Chng	FP Orig	FP Chng	KS Orig	KS Chng	PA Orig	PA Chng	SP Orig	SP Chng	PV	AC	EC	WT
5	1985	NCA		NCA		NCA		NCA		9.04E2		NCA		NCA		NCA	5.92E2	8.75E2	4.4E2	NCA		2.63E4	7.93E4	NCA	2.72E4
	1990	NCA		NCA		NCA		NCA		9.04E2		NCA		2.96E2	5.0E2	5.92E2		7.0E2	2.2E2	NCA		2.55E4	7.83E4	NCA	2.60E4
	2000	NCA		NCA		NCA		NCA		9.04E2		NCA		2.96E2	5.0E2	5.92E2		7.0E2	16.5E1	7.0E2	16.5E1	2.53E4	7.83E4	2.53E4	2.60E4
60	1985	NCA		NCA		NCA	2.6E3	NCA		4.10E3		NCA		NCA		NCA		1.0E4	5.20E3	NCA		3.14E5	9.52E5	NCA	2.47E5
	1990	NCA		NCA		NCA	2.6E3	NCA		4.10E3		NCA		NCA		3.59E3		8.0E3	2.64E3	NCA		3.06E5	9.46E5	NCA	2.39E5
	2000	NCA		NCA		175	2.6E3	NCA		4.10E3		NCA		NCA		3.59E3		8.0E3	1.9E3	NCA		3.04E5	9.40E5	NCA	2.36E5
100	1985	NCA		NCA		NCA	3.6E3	5.61E3		5.61E3		NCA		NCA		NCA		1.8E4	8.8E3	NCA		5.25E5	1.59E6	NCA	3.95E5
	1990	318	3.5E3	NCA		209	3.6E3	5.61E3		5.61E3		NCA		NCA		5.42E3		1.36E4	4.4E3	NCA		5.10E5	1.58E6	NCA	3.82E5
	2000	318	3.5E3	NCA		209	3.6E3	5.61E3		5.61E3		NCA		NCA		5.42E3		1.36E4	3.3E3	NCA		5.05E5	1.57E6	NCA	3.78E5
250	1985	NCA		NCA		NCA	5.0E3	9.74E3		9.74E3		NCA		NCA		NCA		NCA	2.2E4	NCA		1.31E6	3.98E6	NCA	9.31E5
	1990	795	5.2E3	NCA		723	5.0E3	9.74E3		9.74E3		8.78E3		NCA		1.14E4	NCA	3.4E4	1.1E4	NCA		1.28E6	3.95E6	NCA	9.00E5
	2000	795	4.8E3	NCA		723	4.7E3	9.74E3		9.74E3		8.78E3		NCA		1.14E4		3.4E4	8.36E3	NCA		1.26E6	3.93E6	NCA	8.90E5
750	1985	NCA		NCA		2.17E3	1.5E4	2.52E4	1.51E4	2.01E4	1.51E4	NCA		NCA		NCA		NCA	6.6E4	NCA		NCA	NCA	NCA	2.79E5
	1990	2390	15.5E3	NCA		2.17E3	1.5E4	2.52E4	1.51E4	2.01E4	1.51E4	1.01E4		NCA		NCA		1.2E5	3.3E4	NCA		3.04E6	1.10E7	NCA	2.70E5
	2000	2390	14.5E3	NCA		2.17E3	1.4E4	2.52E4	1.51E4	2.01E4	1.51E4	1.01E4		NCA		2.07E4		1.2E5	2.486E4	NCA		3.78E6	1.10E7	NCA	2.67E5
5000	1985	1.60E4	8300	1.01E4	8600	1.45E4	8000	1.30E5		1.30E5		NCA		NCA		NCA		NCA	2.00E5	NCA		NCA	NCA	NCA	NCA
	1990	1.60E4	8300	1.01E4	8600	1.45E4	8000	1.30E5		1.30E5		1.24E5		NCA		NCA		8.0E5	1.00E5	NCA		NCA	NCA	NCA	NCA
	2000	1.60E4	7000	1.01E4	8600	1.45E4	7500	1.30E5		1.30E5		1.24E5		NCA		NCA		8.0E5	7.30E4	NCA		2.52E7	NCA	NCA	NCA

Parameter: System Acquisition Cost Units: 1980 Dollars

PDL ID	Year	RD Orig	RD Chng	CC Orig	CC Chng	MP Orig	MP Chng	TC Orig	TC Chng	TD Orig	TD Chng	AD Orig	AD Chng
5	1985	NCA		NCA		NCA		NCA		4.07E3		NCA	
	1990	NCA		NCA		NCA		NCA		5.3E3		NCA	
	2000	NCA		NCA		NCA		NCA		5.3E3		NCA	
50	1985	NCA		NCA		NCA	3.0E4	NCA		1.01E5		NCA	
	1990	NCA		NCA		NCA	3.0E4	NCA		1.11E5		NCA	
	2000	NCA		NCA		4.11E4	3.0E4	NCA		1.11E5		NCA	
100	1985	NCA		NCA		NCA	6.0E4	3.55E5		2.22E5		NCA	
	1990	6.36E4	6.0E4	NCA		6.06E4	6.0E4	3.91E5		2.40E5		NCA	
	2000	6.36E4	6.0E4	NCA		6.06E4	6.0E4	3.91E5		2.44E5		NCA	
250	1985	NCA		NCA		NCA	2.0E5	7.60E5		4.0E5		NCA	
	1990	1.20E5	2.1E5	NCA		1.22E5	2.0E5	8.45E5		5.20E5		7.61E5	
	2000	1.20E5	2.1E5	NCA		1.22E6	2.0E5	8.45E5		5.20E5		7.61E5	
750	1985	NCA		NCA		2.01E5	4.0E5	1.07E6		1.17E6		NCA	
	1990	2.95E5	4.2E5	NCA		2.01E5	4.0E5	2.06E6		1.29E6		1.05E6	
	2000	2.95E5	4.2E5	NCA		2.01E5	4.0E5	2.06E6		1.29E6		1.05E6	
5000	1985	1.20E6	1.9E6	1.32E6	2.0E6	1.20E6	1.0E6	7.52E6		8.70E6		NCA	
	1990	1.20E6	1.9E6	1.32E6	2.0E6	1.29E6	1.0E6	8.27E6		5.17E6		7.05E6	
	2000	1.20E6	1.9E6	1.32E6	2.0E6	1.29E6	1.0E6	8.27E6		5.17E6		7.05E6	

PDL ID	Year	FP Orig	FP Chng	ES Orig	ES Chng	PA Orig	PA Chng	SP Orig	SP Chng	PV	AC	EC	UT
5	1985	NCA		NCA	9.0E3	7.5E3	2.5E4	NCA		8.15E5	1.19E6	NCA	7.04E4
	1990	4.5E3		4.5E3	9.0E3	5.00E3	1.3E4	NCA		6.92E5	1.01E6	NCA	6.67E4
	2000	4.5E3		4.5E3	9.0E3	3.00E3	3.5E3	4.25E3	2.5E4	6.92E5	1.01E6	6.92E5	6.67E4
50	1985	NCA		NCA	3.0E4	9.00E4	3.0E5	NCA		9.01E6	1.43E7	NCA	4.62E5
	1990	NCA		3.00E4		6.00E4	1.5E5	NCA		8.32E6	1.20E7	NCA	4.37E5
	2000	NCA		3.00E4		3.60E4	4.2E4	NCA		8.32E6	1.20E7	NCA	4.37E5
100	1985	NCA		NCA		1.50E5	5.0E5	NCA		1.63E7	2.30E7	NCA	7.17E5
	1990	NCA		5.00E4		1.00E5	2.5E5	NCA		1.37E7	1.99E7	NCA	6.49E5
	2000	NCA		5.00E4		6.0E4	7.0E4	NCA		1.37E7	1.99E7	NCA	6.49E5
250	1985	NCA		NCA		NCA	1.0E6	NCA		4.00E7	5.95E7	NCA	1.63E6
	1990	NCA		1.25E5	NCA	2.75E5	5.0E5	NCA		3.41E7	4.98E7	NCA	1.55E6
	2000	NCA		1.25E5		1.75E5	1.0E5	NCA		3.41E7	4.98E7	NCA	1.55E6
750	1985	NCA		NCA		NCA	3.0E6	NCA		NCA	NCA	NCA	4.09E6
	1990	NCA		NCA		3.75E5	1.5E6	NCA		1.04E8	1.50E8	NCA	4.65E6
	2000	NCA		3.31E5		3.00E5	5.3E5	NCA		1.04E8	1.50E8	NCA	4.65E6
5000	1985	NCA		NCA		NCA	2E7	NCA		NCA	NCA	NCA	NCA
	1990	NCA		NCA		2.50E6	1E7	NCA		NCA	NCA	NCA	NCA
	2000	NCA		NCA		2.0E6	3.5E6	NCA		6.03E8	NCA	NCA	NCA

Parameter: Annual O&M Costs Units: 1980 Dollars

POL ID	Year	BD Orig	BD Chng	CC Orig	CC Chng	WR Orig	WR Chng	TC Orig	TC Chng	TB Orig	TB Chng	AB Orig	AB Chng	FP Orig	FP Chng	CS Orig	CS Chng	PN Orig	PN Chng	SP Orig	SP Chng	PV	AC	EC	WT
5	1985	NCA		NCA		NCA		NCA		1.21E2		NCA		NCA		NCA	3.0E2	7.50E2	2.5E3	NCA		5.14E4	7.39E4	NCA	3.91E3
	1990	NCA		NCA		NCA		NCA		1.33E2		NCA		2.25E2	5.0E1	2.25E2	3.0E2	5.00E2	1.3E3	NCA		4.40E4	6.31E4	NCA	3.83E3
	2000	NCA		NCA		NCA		NCA		1.33E2		NCA		2.25E2	5.0E1	2.25E2	3.0E2	3.00E2	1.5E2	4.25E2	2.5E3	4.40E4	6.31E4	4.40E4	3.83E3
60	1985	NCA		NCA		NCA	1.6E3	NCA		1.10E2	1.1E3	NCA		NCA		NCA		9.00E3	3.0E4	NCA		6.19E5	8.00E5	NCA	3.94E4
	1990	NCA		NCA		NCA	1.6E3	NCA		1.21E3		NCA		NCA		1.50E2	2.97E3	6.00E3	1.5E4	NCA		5.29E5	7.50E5	NCA	3.00E4
	2000	NCA		NCA		2.05E3	1.6E3	NCA		1.21E3		NCA		NCA		1.50E2	2.97E3	3.60E3	4.2E3	5.10E3		5.29E5	7.50E5	NCA	3.00E4
100	1985	NCA		NCA		NCA	2.6E3	3.25E3		2.03E3		NCA		NCA		NCA		1.50E4	5.0E4	NCA		1.03E6	1.40E6	NCA	6.40E4
	1990	3.10E3		NCA		3.03E3	2.6E3	3.50E3		2.03E3		NCA		NCA		2.50E3	4.53E3	1.00E4	2.5E4	NCA		8.72E5	1.24E6	NCA	6.29E4
	2000	3.10E3		NCA		3.03E3	2.6E3	3.50E3		2.03E3		NCA		NCA		2.50E3	4.53E3	6.00E3	7.0E3	NCA		8.72E5	1.24E6	NCA	6.29E4
250	1985	NCA		NCA		NCA	5.5E3	5.04E3		3.65E3		NCA		NCA		NCA		NCA	1.0E5	NCA		2.37E6	3.70E6	NCA	1.60E5
	1990	1.00E4	5.0E3	NCA		6.09E3	5.5E3	6.42E3		4.01E3		5.70E3		NCA		6.25E3	NCA	2.75E4	5.0E4	NCA		2.17E6	3.11E6	NCA	1.56E5
	2000	1.00E4	5.0E3	NCA		6.09E3	5.5E3	6.41E3		4.01E3		5.70E3		NCA		6.25E3	1.125E4	1.25E4	1.0E4	NCA		2.17E6	3.11E6	NCA	1.56E5
750	1985	NCA		NCA		1.41E4	1.5E4	1.05E4		1.16E4		NCA		NCA		NCA		NCA	3.0E5	NCA		NCA	NCA	NCA	4.79E5
	1990	1.40E4	1.3E4	NCA		1.41E4	1.5E4	2.03E4		1.27E4		1.00E4		NCA		NCA		3.75E4	1.5E5	NCA		6.62E6	9.30E6	NCA	4.67E5
	2000	1.40E4	1.3E4	NCA		1.42E4	1.5E4	2.03E4		1.27E4		1.00E4		NCA		1.66E4	3.375E4	3.00E4	5.3E4	NCA		6.62E6	9.30E6	NCA	4.67E5
5000	1985	6.00E4	8.11E4	6.37E4	8.13E4	5.97E4	7.7E4	2.95E5		1.04E5		NCA		NCA		NCA		NCA	2E6	NCA		NCA	NCA	NCA	NCA
	1990	6.00E4	8.11E4	6.37E4	8.1E4	5.97E4	7.7E4	3.24E5		2.03E5		2.92E5		NCA		NCA		2.50E4	1E6	NCA		NCA	NCA	NCA	NCA
	2000	6.00E4	8.11E4	6.37E4	8.1E4	5.97E4	7.7E4	3.24E5		2.03E5		2.92E5		NCA		NCA		2.00E5	3.5E5	NCA		4.35E7	NCA	NCA	NCA

Parameter: Life Cycle Cost Units: 1980 Cents/kwh

PBL ID	Year	BD Orig	BD Chng	CC Orig	CC Chng	WR Orig	WR Chng	TC Orig	TC Chng	TB Orig	TB Chng	AB Orig	AB Chng	FP Orig	FP Chng	KS Orig	KS Chng	PA Orig	PA Chng	SP Orig	SP Chng	PV	AC	EC	WT
5	1985	NCA		NCA		NCA		NCA		4.97		NCA		NCA		NCA	10.55	5.41	10.69	NCA		158.9	230.7	NCA	13.2
	1990	NCA		NCA		NCA		NCA		4.84		NCA		4.23	4.98	4.39	7.68	4.53	6.99	NCA		135.3	196.2	NCA	12.6
	2000	NCA		NCA		NCA		NCA		4.84		NCA		4.23	4.10	4.39	5.25	3.91	4.10	3.56	9.65	135.3	196.2	135.3	12.6
60	1985	NCA		NCA		NCA	14.63	NCA		4.86		NCA		NCA		NCA		5.41	11.05	NCA		158.9	231.1	NCA	8.43
	1990	NCA		NCA		NCA	14.63	NCA		4.82		NCA		NCA		NCA	4.83	4.54	6.71	NCA		133.8	194.3	NCA	8.11
	2000	NCA		NCA		2.37	12.20	NCA		4.82		NCA		NCA		4.03	3.88	3.93	3.99	NCA		133.8	194.3	NCA	8.11
100	1985	NCA		NCA		NCA	8.43	5.58		5.15		NCA		NCA		NCA		5.13	10.76	NCA		159.6	230.8	NCA	8.05
	1990	1.42	1.90	NCA		2.15	8.43	5.60		5.13		NCA		NCA		NCA	4.79	4.38	6.66	NCA		134.0	193.2	NCA	7.51
	2000	1.42	1.90	NCA		2.15	7.94	5.60		5.13		NCA		NCA		4.03	3.84	3.35	3.76	NCA		134.0	193.2	NCA	7.51
250	1985	NCA		NCA		NCA	2.94	5.14		4.77		NCA		NCA		NCA		NCA	8.98	NCA		158.9	230.8	NCA	7.59
	1990	1.31	1.70	NCA		1.86	2.94	5.22		4.73		3.14		NCA		NCA		4.25	5.95	NCA		133.8	193.5	NCA	7.30
	2000	1.31	1.76	NCA		1.86	2.71	5.22		4.73		3.14		NCA		4.04	3.84	3.42	3.74	NCA		133.8	193.5	NCA	7.30
750	1985	NCA		NCA		1.97	2.24	4.52		4.38		NCA		NCA		NCA		NCA	8.90	NCA		NCA	NCA	NCA	7.58
	1990	1.21	1.48	NCA		1.64	2.24	4.37		4.34		3.41		NCA		NCA		3.79	5.95	NCA		134.0	194.4	NCA	7.29
	2000	1.21	1.48	NCA		1.64	2.11	4.37		4.34		3.41		NCA		2.83	2.74	3.31	3.79	NCA		134.0	194.4	NCA	7.29
5000	1985	1.21	2.84	2.71	7.06	1.61	4.05	3.87		3.80		NCA		NCA		NCA		NCA	.14	NCA		NCA	NCA	NCA	NCA
	1990	1.07	2.84	2.71	7.06	1.44	3.80	3.88		3.81		1.77		NCA		NCA		3.43	.08	NCA		NCA	NCA	NCA	NCA
	2000	1.07	2.84	2.21	5.02	1.44	3.80	3.88		3.81		1.77		NCA		NCA		3.31	.04	NCA		133.6	NCA	NCA	NCA

Parameter: Start-up Time Units: Minutes

POL ID	Year	BD Orig	BD Chng	CC Orig	CC Chng	MR Orig	MR Chng	TC Orig	TC Chng	TD Orig	TD Chng	AD Orig	AD Chng	FP Orig	FP Chng	KS Orig	KS Chng	PA Orig	PA Chng	SP Orig	SP Chng	PV	AC	EC	UT
5	1985	NCA		NCA		NCA		NCA		2	.17	NCA		NCA		NCA	1.5	40	20	NCA		5	5	NCA	1.67E1
	1990	NCA		NCA		NCA		NCA		2	.17	NCA		0.25	10	0.25	1.5	40	15	NCA		5	5	NCA	1.67E1
	2000	NCA		NCA		NCA		NCA		2	.17	NCA		0.25	10	0.25	1.5	40	5	40	5	5	5	5	1.67E1
60	1985	NCA		NCA		NCA		NCA		2	.17	NCA		NCA		NCA		60	30	NCA		5	5	NCA	2.00
	1990	NCA		NCA		NCA		NCA		2	.17	NCA		NCA		0.25	1.5	60	20	NCA		5	5	NCA	2.00
	2000	NCA		NCA		1.0		NCA		2	.17	NCA		NCA		0.25	1.5	60	10	NCA		5	5	NCA	2.00
100	1985	NCA		NCA		NCA		2	.17	2	.17	NCA		NCA		NCA		120	30	NCA		5	5	NCA	2.00
	1990	1.0		NCA		1.0		2	.17	2	.17	NCA		NCA		0.25	1.5	120	30	NCA		5	5	NCA	2.00
	2000	1.0		NCA		1.0		2	.17	2	.17	NCA		NCA		0.25	1.5	120	30	NCA		5	5	NCA	2.00
250	1985	NCA		NCA		NCA		2	.17	2	.17	NCA		NCA		NCA		NCA	30	NCA		5	5	NCA	5.00
	1990	1.0		NCA		1.0		2	.17	2	.17	2	.17	NCA		0.25		120	30	NCA		5	5	NCA	5.00
	2000	1.0		NCA		1.0		2	.17	2	.17	2	.17	NCA		0.25	1.5	120	30	NCA		5	5	NCA	5.00
750	1985	NCA		NCA		1.0		2	.17	2	.17	NCA		NCA		NCA		NCA	30	NCA		NCA	NCA	NCA	5.00
	1990	1.0		NCA		1.0		2	.17	2	.17	2	.17	NCA		NCA		150	30	NCA		5	5	NCA	5.00
	2000	1.0		NCA		1.0		2	.17	2	.17	2	.17	NCA		0.25	1.5	150	30	NCA		5	5	NCA	5.00
5000	1985	1.0		1.0		1.0		2		2		NCA		NCA		NCA		NCA	30	NCA		NCA	NCA	NCA	NCA
	1990	1.0		1.0		1.0		2		2		2		NCA		NCA		100	30	NCA		NCA	NCA	NCA	NCA
	2000	1.0		1.0		1.0		2		2		2		NCA		NCA		100	30	NCA		5	NCA	NCA	NCA

Parameter: Annual Fuel Cost (Diesel Fuel) Units: 1980 Dollars

PGL kW	Year	RO Orig	RO Chng	CC Orig	CC Chng	WA Orig	WA Chng	TC Orig	TC Chng	TB Orig	TB Chng	AB Orig	AB Chng
5	1985	NCA		NCA		NCA		NCA		3.92E3		NCA	
	1990	NCA		NCA		NCA		NCA		3.73E3		NCA	
	2000	NCA		NCA		NCA		NCA		3.73E3		NCA	
60	1985	NCA		NCA		NCA	1.53E5	NCA		4.13E4		NCA	
	1990	NCA		NCA		NCA	1.53E5	NCA		3.93E4		NCA	
	2000	NCA		NCA		1.95E4	1.26E5	NCA		3.93E4		NCA	
100	1985	NCA		NCA		NCA	1.47E5	5.70E4		6.72E4		NCA	
	1990	1.57E4	5.85E4	NCA		2.96E4	1.47E5	5.43E4		6.41E4		NCA	
	2000	1.57E4	5.85E4	NCA		2.96E4	1.32E5	5.43E4		6.41E4		NCA	
250	1985	NCA		NCA		NCA	3.41E5	1.42E5		1.61E5		NCA	
	1990	3.93E4	1.40E5	NCA		6.57E4	3.41E5	1.36E5		1.53E5		5.03E4	
	2000	3.93E4	1.40E5	NCA		6.57E4	3.03E5	1.36E5		1.53E5		5.03E4	
750	1985	NCA		NCA		2.26E5	7.74E5	3.9E5		4.60E5		NCA	
	1990	1.10E5	4.33E5	NCA		1.01E5	7.74E5	3.72E5		4.39E5		2.41E5	
	2000	1.10E5	4.33E5	NCA		1.01E5	7.20E5	3.72E5		4.39E5		2.41E5	
5000	1985	9.09E5	2.79E6	2.29E6	3.41E6	1.29E6	4.26E6	2.41E6		2.84E6		NCA	
	1990	7.85E5	2.79E6	2.29E6	3.41E6	1.13E6	4.02E6	2.30E6		2.72E6		4.72E5	
	2000	7.85E5	2.79E6	1.83E6	2.76E6	1.13E6	4.02E6	2.30E6		2.72E6		4.72E5	

PGL kW	Year	FP Orig	FP Chng	ES Orig	ES Chng	PA Orig	PA Chng	SP Orig	SP Chng	PV	AC	EC	HT
5	1985	NCA		NCA	5.79E3	3.30E3	3.33E3	NCA		0	0	NCA	0
	1990	3.16E3	3.06E3	3.31E3	4.63E3	3.11E3	3.06E3	NCA		0	0	NCA	0
	2000	3.16E3	3.21E3	3.31E3	3.50E3	2.97E3	2.80E3	2.37E3		0	0	0	0
60	1985	NCA		NCA		4.06E4	4.0E4	NCA		0	0	NCA	0
	1990	NCA		3.97E4	4.34E4	3.74E4	3.51E4	NCA		0	0	NCA	0
	2000	NCA		3.97E4	3.662E4	3.58E4	3.33E4	NCA		0	0	NCA	0
100	1985	NCA		NCA		6.24E4	6.12E4	NCA		0	0	NCA	0
	1990	NCA		6.63E4	7.21E4	5.94E4	5.76E4	NCA		0	0	NCA	0
	2000	NCA		6.63E4	6.07E4	5.27E4	5.13E4	NCA		0	0	NCA	0
250	1985	NCA		NCA		NCA	1.53E5	NCA		0	0	NCA	0
	1990	NCA		1.66E5	NCA	1.40E5	1.44E5	NCA		0	0	NCA	0
	2000	NCA		1.66E5	1.32E5	1.31E5	1.26E5	NCA		0	0	NCA	0
750	1985	NCA		NCA		NCA	4.59E5	NCA		NCA	NCA	NCA	0
	1990	NCA		NCA		4.45E5	4.32E5	NCA		0	0	NCA	0
	2000	NCA		3.37E5	4.53E5	3.94E5	3.07E5	NCA		0	0	NCA	0
5000	1985	NCA		NCA		NCA	3.02E6	NCA		NCA	NCA	NCA	NCA
	1990	NCA		NCA		2.96E6	2.86E6	NCA		NCA	NCA	NCA	NCA
	2000	NCA		NCA		2.63E6	2.55E6	NCA		NCA	NCA	NCA	NCA

Parameter: Annual Fuel Consumption Units: Btu

POL ID	Year	BO Orig	BO Chng	CC Orig	CC Chng	MR Orig	MR Chng	TC Orig	TC Chng	TD Orig	TD Chng	AB Orig	AB Chng	FP Orig	FP Chng	KS Orig	KS Chng	PA Orig	PA Chng	SP Orig	SP Chng	PV	AC	EC	WT
5	1985	NCA		NCA		NCA		NCA		4.55E8		NCA		NCA		NCA	6.72E8	3.83E8	3.87E8	NCA		0	0	NCA	0
	1990	NCA		NCA		NCA		NCA		4.33E8		NCA		NCA	4.40E8	3.04E8	5.37E8	3.53E8	3.51E8	NCA		0	0	NCA	0
	2000	NCA		NCA		NCA		NCA		4.33E8		NCA		1.47E9	3.65E8	3.04E8	4.07E8	3.37E8	3.33E8	2.69E8		0	0	0	0
60	1985	NCA		NCA		NCA	1.0E10	NCA		4.79E9		NCA		NCA		NCA		4.60E9	4.59E9	NCA		0	0	NCA	0
	1990	NCA		NCA		NCA	1.0E10	NCA		4.56E9		NCA		NCA		4.61E9	5.07E9	4.24E9	4.05E9	NCA		0	0	NCA	0
	2000	NCA		NCA		7.88E9	1.44E10	NCA		4.56E9		NCA		NCA		4.61E9	4.75E9	4.06E9	3.87E9	NCA		0	0	NCA	0
100	1985	NCA		NCA		NCA	1.71E10	6.61E9		7.00E9		NCA		NCA		NCA		7.00E9	7.14E9	NCA		0	0	NCA	0
	1990	6.36E9	6.0E9	NCA		1.20E10	1.71E10	6.30E9		7.44E9		NCA		NCA		7.69E9	8.37E9	6.73E9	6.75E9	NCA		0	0	NCA	0
	2000	7.36E9	6.0E9	NCA		1.20E10	1.53E10	6.30E9		7.44E9		NCA		NCA		7.69E9	7.05E9	5.90E9	5.94E9	NCA		0	0	NCA	0
250	1985	NCA		NCA		NCA	3.96E10	1.65E10		1.07E10		NCA		NCA		NCA		NCA	1.00E10	NCA		0	0	NCA	0
	1990	1.59E10	1.71E10	NCA		2.66E10	3.96E10	1.50E10		1.70E10		5.03E9		NCA		1.92E10	NCA	1.60E10	1.71E10	NCA		0	0	NCA	0
	2000	1.59E10	1.71E10	NCA		2.66E10	3.51E10	1.50E10		1.70E10		5.03E9		NCA		1.92E10	1.76E10	1.49E10	1.53E10	NCA		0	0	NCA	0
750	1985	NCA		NCA		9.13E10	9.0E10	4.53E10		5.34E10		NCA		NCA		NCA		NCA	5.31E10	NCA		NCA	NCA	NCA	0
	1990	4.77E10	4.95E10	NCA		7.34E10	9.0E10	4.31E10		5.09E10		2.0E10		NCA		NCA		5.04E10	5.04E10	NCA		0	0	NCA	0
	2000	4.77E10	4.95E10	NCA		7.34E10	8.37E10	4.31E10		5.09E10		2.0E10		NCA		5.77E10	5.27E10	4.47E10	4.50E10	NCA		0	0	NCA	0
5000	1985	3.60E11	3.24E11	3.91E11	3.96E11	5.24E11	4.95E11	2.00E11		3.30E11		NCA		NCA		NCA		NCA	3.51E11	NCA		NCA	NCA	NCA	NCA
	1990	3.10E11	3.24E11	3.91E11	3.96E11	4.50E11	4.60E11	2.67E11		3.15E11		5.40E10		NCA		NCA		3.36E11	3.33E11	NCA		NCA	NCA	NCA	NCA
	2000	3.10E11	3.24E11	3.12E11	3.15E11	4.50E11	4.60E11	2.67E11		3.15E11		5.40E10		NCA		NCA		2.90E11	2.97E11	NCA		0	NCA	NCA	NCA

Parameter: Volume Units: Cubic Feet

POL No	Year	NO Orig	NO Chng	CC Orig	CC Chng	NR Orig	NR Chng	TC Orig	TC Chng	TD Orig	TD Chng	AB Orig	AB Chng	FP Orig	FP Chng	KS Orig	KS Chng	PA Orig	PA Chng	SP Orig	SP Chng	PV	AC	EC	WT
5	1985	NCA		NCA		NCA		NCA		NCA		NCA		NCA		NCA	2.5E1	12.0	3.5E1	NCA		6.53E5	9.00E5	NCA	1.40E3
	1990	NCA		NCA		NCA		NCA		NCA		NCA		1.71E1	2.0E1	1.71E1	2.0E1	10.0	2.0E1	NCA		6.53E5	9.00E5	NCA	1.40E3
	2000	NCA		NCA		NCA		NCA		NCA		NCA		1.71E1	2.0E1	1.71E1	2.0E1	10.0	3.5E0	10.0	3.5	6.53E5	9.00E5	6.53E5	1.40E3
60	1985	NCA		NCA		NCA	4.0E1	NCA		NCA		NCA		NCA		NCA		420	4.2E2	NCA		7.84E6	1.10E7	NCA	5.03E4
	1990	NCA		NCA		NCA	4.0E1	NCA		NCA		NCA		NCA		8.92E1	1.0E2	340	2.4E2	NCA		7.84E6	1.10E7	NCA	3.02E4
	2000	NCA		NCA		3.50E1	4.0E1	NCA		NCA		NCA		NCA		8.92E1	1.0E2	340	4.2E1	NCA		7.84E6	1.10E7	NCA	5.02E4
100	1985	NCA		NCA		NCA	4.0E1	1.11E2		1.11E2		NCA		NCA		NCA		700	7.0E2	NCA		1.31E7	1.96E7	NCA	1.04E5
	1990	4.84E1	6.0E1	NCA		4.5E1	4.0E1	1.11E2		1.11E2		NCA		NCA		1.22E2	2.25E2	650	4.0E1	NCA		1.31E7	1.96E7	NCA	1.04E5
	2000	4.84E1	6.0E1	NCA		4.5E1	4.0E1	1.11E2		1.11E2		NCA		NCA		1.22E2	2.25E2	650	7.0E1	NCA		1.31E7	1.96E7	NCA	1.04E5
250	1985	NCA		NCA		NCA	6.0E1	1.91E2		1.91E2		NCA		NCA		NCA		NCA	1.75E3	NCA		3.26E7	4.96E7	NCA	3.08E5
	1990	1.12E2	8.0E1	NCA		8.45E1	6.0E1	1.91E2		1.91E2		1.72E2		NCA		2.10E2	NCA	2000	1.0E3	NCA		3.26E7	4.96E7	NCA	3.08E5
	2000	1.12E2	8.0E1	NCA		8.45E1	6.0E1	1.91E2		1.91E2		1.72E2		NCA		2.10E2	5.0E2	2000	1.75E2	NCA		3.26E7	4.96E7	NCA	3.08E5
750	1985	NCA		NCA		1.42E2	2.2E2	3.07E2		3.07E2		NCA		NCA		NCA		NCA	5.25E3	NCA		NCA	NCA	NCA	1.16E6
	1990	1.65E2	2.4E2	NCA		1.42E2	2.2E2	3.07E2		3.07E2		3.40E2		NCA		NCA		6.0E2	3.0E3	NCA		9.79E7	1.47E8	NCA	1.16E6
	2000	1.65E2	2.4E2	NCA		1.42E2	2.2E2	3.07E2		3.07E2		3.40E2		NCA		4.26E2	9.15E2	6.0E3	5.25E2	NCA		9.79E7	1.47E8	NCA	1.16E6
5000	1985	2.00E2	370	2.29E2	390	1.73E2	350	2.57E3		2.57E3		NCA		NCA		NCA		NCA	3.5E4	NCA		NCA	NCA	NCA	NCA
	1990	2.00E2	370	2.29E2	390	1.73E2	350	2.57E3		2.57E3		2.31E3		NCA		NCA		1.25E5	2.0E4	NCA		NCA	NCA	NCA	NCA
	2000	2.00E2	370	2.29E2	390	1.73E2	350	2.57E3		2.57E3		2.31E3		NCA		NCA		1.25E5	3.5E5	NCA		6.53E8	NCA	NCA	NCA

Parameter: Designated Fuel

POL ID	Year	HD Orig	HD Chng	CC Orig	CC Chng	WB Orig	WB Chng	TC Orig	TC Chng	TD Orig	TD Chng	AB Orig	AB Chng	FP Orig	FP Chng	ES Orig	ES Chng	PA Orig	PA Chng	SP Orig	SP Chng	PV	AC	EC	WT
5	1985	NCA		NCA		NCA		D		D		NCA		D	NCA	D		JP-4	MULTI	NCA		S	S	NCA	W
	1990	NCA		NCA		NCA		D		D		D	NCA	D		D		JP-4	MULTI	JP-4	NCA	S	S	S	W
	2000	NCA		NCA		NCA		D		D		D	NCA	D		D		JP-4	MULTI	JP-4	MULTI(1)	S	S	S	W
60	1985	NG	NCA	D		NG	D	D		D		NCA		D	NCA	D	NCA	JP-4	MULTI	NCA		S	S	NCA	W
	1990	NG	NCA	D		NG	D	D		D		D	NCA	D	NCA	D		JP-4	MULTI	JP-4	NCA	S	S	S	W
	2000	NG	NCA	D		NG	D	D		D		D	NCA	D	NCA	D		JP-4	MULTI	JP-4	NCA	S	S	S	W
100	1985	NG	NCA	D		NG		D		D		NCA		D	NCA	D	NCA	JP-4	MULTI	NCA		S	S	NCA	W
	1990	NG	D	D		NG		D		D		D	NCA	D	NCA	D		JP-4	MULTI	JP-4	NCA	S	S	S	W
	2000	NG	S	D		NG		D		D		D	NCA	D	NCA	D		JP-4	MULTI	JP-4	NCA	S	S	S	W
250	1985	NG	NCA	D		NG		D		D		NCA		D	NCA	D	NCA	JP-4	MULTI	NCA		S	S	NCA	W
	1990	NG		D		NG		D		D		D		D	NCA	D	NCA	JP-4	MULTI	JP-4	NCA	S	S	S	W
	2000	NG		D		NG		D		D		D		D	NCA	D		JP-4	MULTI	JP-4	NCA	S	S	S	W
750	1985	NG		R		NG		D		D		NCA		R	NCA	R	NCA	JP-4	MULTI	NCA		S	S	NCA	W
	1990	NG		D		NG		D		D		D		R	NCA	R	NCA	JP-4	MULTI	JP-4	NCA	S	S	S	W
	2000	NG		R		NG		D		D		D		R	NCA	R	NCA	JP-4	MULTI	JP-4	NCA	S	S	S	W
3000	1985	NG		D		NG		D		D		NCA		NCA		NCA		JP-4	MULTI	NCA		S	S	NCA	W
	1990	NG		R		NG		D		D		D		NCA		NCA		JP-4	MULTI	JP-4	NCA	S	S	S	W
	2000	NG		R		NG		D		D		D		NCA		NCA		JP-4	MULTI	JP-4	NCA	S	S	S	W

D - diesel fuel
R - residual fuel
S - sunlight
W - wind

Appendix B

Responses to Discussion Questions

Appendix B
Responses to Discussion Questions

1. Summary of General Concerns by MEP Personnel About Present Conditions and Equipment:

- MEP generators are "too sophisticated" to be maintained by personnel assigned to MEP units. (This usually refers to electronic versus mechanical controls).

- Power cable systems and connectors need to be improved.

- General maintenance proficiency skills are being degraded because commercial electric power is being substituted for JP-4 due to monetary constraints. (This refers to the use of MD-4 motor generators which convert 60 to 400 cycle AC current to replace gas turbine engine driven MEP units in tactical precise applications).

- The system IR signature and generator noise would be easily detected by hostile forces. (This topic was of high concern to a few individuals, but was not of general concern to respondents).

- The availability of JP-4 fuel is of concern OCONUS, where reliance on the Army logistic fuel supply may affect sustained operations at deployed locations.

- There is a perceived inadequacy of technical training courses, especially OCONUS.

- There are inadequacies and deficiencies in technical bulletins, technical orders, and technical manuals.

2. Concerns of MEP Personnel by Mission Area:

a. SAC Flightlines. Unstable frequency output and power fluctuations, mobility and ease of movement of the MEP units, non-availability of spare parts, and the ability to start and move the MEP equipment in extreme cold weather are the principal concerns noted by SAC flightline (OMS, FMS, AMS, and MMS) personnel. There appears to be an inadequacy of equipment technical data when MEP units are received at the field locations. The substitution of larger fuel tanks on the units plus better lubrication techniques would reduce the number of MEP equipment changes during extended flightline maintenance operations. These improvements would provide a better consistency in power output, which is sometimes lost, when power units must be changed during operations.

b. MAC Flightlines. The lack of an adequate MEP self-propulsion system, the weight and bulkiness of the units, and problems involving the availability of spare parts are the principal concerns expressed by MAC flightline (FMS, OMS, and AMS) personnel. The operating range to provide MEP support to aircraft from a stationary position should be extended by lengthening the MEP cables. This change would improve manpower efficiency by permitting more rapid disconnect and reconnect capability when supporting flight operations. It would also improve personal safety and reduce noise hazards to flightline personnel. The fuel tanks of future MEP equipment should be configured to accomodate increased mobility requirements.

c. TAC Flightlines. Frequency and power fluctuations, fuel consumption, and noise hazards during MEP unit operation were particular concerns of TAC flightline personnel (EMS and AGS), as were concerns regarding the non-availability of spare parts (e.g. governors, fuel controls, etc.). The proliferation of generator types has required duplicative parallel and backup units as well as impacting on and complicating the OJT requirements of tactical units. The WRSK, or fly-away, kits were identified as being designed for aircraft parts and do not include material for aircraft support equipment. Most parts for MEP equipment which can be repaired in the base level maintenance shops can only be tested by reinstalling the part back into the MEP unit. (This indicates that either appropriate test equipment is unavailable or that the experience or training level of the MEP maintainer needs to be enhanced).

One respondent suggests that a family of tactical precise MEP units between 10 kW - 75 kW, should be available, which are small, mobile, and can be transported in the bed of a M35 vehicle. Parts for this family of units should be interchangeable whenever possible.

d. USAFE. Unstable voltage and frequency outputs were the principal concerns of USAFE flightline (EMS, AGS, and CRS) personnel. The MEP units' weight and size hindered the positioning and movement of the units. There should be separate designs for maintenance power units and for launch power units. Launch power does not require the same power quality.

e. PACAF. The ability to easily position and move MEP units around the flightline area and the stability and quality of electric output, power fluctuation, frequency deviations, and intermittent power interruptions were the principal concerns of PACAF flightline (EMS, AGS, and CRS) personnel. Power fluctuations and frequency deviations had caused electronic equipment to burn internally, fail, or cause system malfunctions.

f. TACS Personnel. The principal concerns of TACS personnel regarding current MEP equipment were that the generators are too sophisticated to maintain by assigned personnel, consume to much fuel, are too heavy and bulky, and that the IR signature and engine noise would be easily detected by hostile forces. Commercial electric power often is often being used due to monetary constraints involving JP-4 fuel costs. This "real world" economic tradeoff, however, reduces the training proficiency of maintenance personnel. There is a concern regarding availability of fuel worldwide. Although the MEP 404 is supposed to be a multi-fuel unit, maintainers believe the use of JP-4 is essential to keep the unit in continuous operation if deployed. Since tactical air control is often reliant of Army supply, the availability of this fuel is a concern.

The following comments pertain to development of future MEP equipment or capabilities to support TACS requirements:

The equipment should be small, compact, light, and easy to camouflage. The engine should have a true multi-fuel capability and would accept even low octane fuels which might be the only fuel available in some remote locations OCONUS. The generator(s) should have an increased fuel tank capacity to sustain continuous operations. The critical components of the generator should be protected from damage by sand or dust and the entire MEP unit should be easily adaptable to all extreme environmental conditions--particularly heat, rain, sand and cold temperatures. Power cables should be designed to be easily connected, possibly by cross-threading, and detached, and the connectors should be standardized for interchangable use. MEP units developed to support the tactical air request net should be capable of being fitted into or mounted in the rear of the M151 jeep or its successor.

g. Other Mission Areas The availability of, and long lag time to receive, spare parts for MEP units, especially for older models, was the foremost concern of ATC flightline (OMS and FMS) personnel. The accessibility to components for trouble-shooting and repair and the noise hazard, even when wearing ear plugs, were other concerns. According to an AFCC respondent, new MEP series generators are "utility" models rather than precision generators and do not adequately support the load requirements of communications equipment. The unit vibrations effect performance and lifespan of communication components and circuits.

3. Field Comments Regarding Deficiencies of Specific MEP Systems.

a. MEP 356A (A/M 32A-60 Generator; 60 kW, 400 Hz)

a) Difficult to position by one person.

b) "Impossible" to position easily around aircraft during ice and snow.

c) Requires frequent refueling because of high fuel consumption.

d) High noise hazard to hearing and for communication with other maintenance projects.

e) Develop a field kit (seals, bearings, and brushes) for the A/M 32A-60A Boost Pump.

f) Will not always carry aircraft load.

g) Need longer power cable of at least 80-120 feet. Larger cable would eliminate some equipment moves due to cable length.

h) Poor reliability of engine and fuel control units.

i) High failure rate on fuel system components.

j) Equipment cannot supply 60 Hz power which is sometimes required.

k) Sets are designed to cut off electric power at 1180°F which is a problem in wet environments.

l) Bleed air ducts and scuff covers burn frequently.

m) Unit is only capable of operating for 4-5 hours without refueling.

2) <u>MEP 357A (A/M 32A-86 Hobart Generator; 48 kW, 400 Hz)</u>

a) Often will not reset after self-shut down.

b) Needs longer power cable of at least 80-120 feet. A longer cable would eliminate some equipment moves due to cable length.

c) The electrical control board malfunctions in wet weather. The unit must be dried out in the AGE shop before being returned to flightline.

d) Purchases of Hobart parts through Hobart dealers require two to six weeks.

e) Too heavy.

f) The voltage drops under a heavy load causing total power loss to the aircraft and its avionic systems. Unit shuts down without warning causing excessive operational and trouble-shooting due to equipment damage.

g) Needs a warning system to indicate low fuel level so unit does not shut down without warning. Takes too long, 35-45 minutes, to refuel.

h) Does not have a self-contained heating system for extreme cold weather starting since the current heating system requires commercial 110V AC for operation.

i) Lacks 28V DC capability which is a problem for providing support to transient aircraft.

j) Some units do not have a large enough current capacity for the initial surge current requirement of the defensive fire control system (max surge 40,000v amperes for four seconds IAW IB-52H-2-2-2).

k) Difficult to start at temperatures below zero degrees.

3) MEP 404A/B (A/E 24U-8 Power Plant 60/120 kW, 400 Hz) & MEP 404B Generator (60 kW, 400 Hz)

a) The control circuits can shut down if a HF radio is operating near by. The electric governor can sometimes pick up radio frequency from the MRC-108B which causes the A/E 240-8 generator to surge.

b) Very high fuel consumption. Lacks true multi-fuel capability.

c) The connecting power cables from the MEP units to the communications vans are difficult to disconnect.

d) IR emissions are high and probably very easy to detect.

e) Very difficult to obtain critical parts (i.e. wiring harness, fuel manifold, etc.).

f) The bearings in the T62T-32 engines have a high failure rate.

g) Tactical units must acquire, transport, or store JP-4 fuel for this type of MEP equipment in addition to gasoline and diesel fuel for vehicles and other equipment.

h) The unit lacks a capability to function in certain combat environmental conditions such as blowing sand, snow, and weather extremes causing power failures.

i) The complexity and difficulty in trouble-shooting and repair of the electronic control/protective circuit cards are a major weakness of the unit.

j) The operating control circuits are too critical. Numerous "shut downs" occur for no apparent reason and the unit comes back on-line at restart. The units require paralleling to insure that communications equipment has constant power.

k) The "-8" is too sophisticated to be used as a mobility unit. The unit requires too much training to become proficient to maintain the system.

4) MEP-116B Diesel Generator (100 kW, 400 Hz)

a) Too heavy, which causes mobility and towing problems.

b) Lacks a storage compartment, or brackets, for the output cables.

5) <u>MEP-016A/017A Generators (3 kW, 60 Hz/5 kW, 60 Hz)</u>

Not designed for continuous operation.

6) <u>MEP-25/26 Generators (1.5 kW, DC/3 kW, DC)</u>

a) Noisy, heavy, bulky, and difficult to maintain.

b) Difficult to start.

c) Uses considerable fuel

4. <u>Other Field Comments and Considerations.</u>

1) <u>Training</u>

a) Adequacy of technical school training needs to be reviewed. Entry level airmen require 6-9 months of OJT after graduation from a technical school before becoming proficient on generator use and maintenance.

b) Lack of training classes overseas greatly increase OJT training periods. Personnel in overseas areas are just obtaining individual proficiency when they are rotated.

c) The proliferation of generator types has limited the ability of formal technical school training to produce a high proficiency level. An extensive amount of time must be expended to familiarize and train newly assigned personnel to a satisfactory proficiency level.

d) The use of several types of generators which burn different types of fuel creates logistic problems in the field and increases training problems at all echelons.

e) High fuel consumption and costs force users to operate motor generators on commercial power for most operations to stay within budget constraints. This action decreases the proficiency training of support equipment personnel on MEP equipment.

f) Training modules for new test equipment need to be developed for OJT maintenance of generators converted from mechanical relays to solid state circuitry.

2) <u>Technical Bulletins, Orders, and Manuals.</u>

a) An illustrated parts breakdown for solid state control boards does not exist. Most boards are coded "XF3". A depot repair capability does not exist for solid state components.

b) Technical orders lack reassembly and repair instructions. Orders need to better describe and depict circuit detail theory.

c) Repair procedures in technical orders are very vague and inadequate in the logic sequencing of assembly order.

d) A deficiency exists in the availability of technical data at the user level regarding solid state circuits presently being used in diesel-powered generator sets.

e) Technical manuals should address the relationship between mechanical and electrical sub-systems, and the entire MEP unit (i.e. engine, generator, electrical components, etc.).

3) Fuel.

a) Commercial electric power often is used instead of JP-4 to power the MEP 404, due to monetary constraints. This degrades actual training available for support equipment personnel and increases maintenance burdens due to additional systems having to be maintained.

b) MEP units using diesel may experience malfunctions in cold weather. Low grade diesel freezes at -6 degrees Centigrade and most field, or combat support, units are supplied with low grade diesel fuel.

c) MEP engines should be developed to have a multi-fuel capability with a lengthly MTBF and MTBO using each fuel source. This enhanced capability would allow bare base units to use whatever local fuel(s) is available.

4) Cables.

a) Review cable manufacturing techniques to determine if more solid, or riveted head, AC cable heads can be made available. These types of "solid" cable heads would be preferable to those in use which have a screw to hold the cable to the head.

b) The four wire power cable system provided with present MEP equipment does not provide adequate ground fault and signal ground isolation capabilities. A five wire power cable system should be developed which would eliminate most grounding problems associated with MEP generators.

c) Common plugs should be installed to the load terminals to facilitate power load connecting.

5) Miscellaneous Concerns

a) Different types of MEP units are required to handle the different types of munitions handling equipment.

b) The AGM-69A SRAM System is extremely sensitive to power fluctuations. A malfunctioning power unit may cause erroneous fault indicators in the SRAM System while still providing satisfactory power for other aircraft systems. This often has led to considerable maintenance effort before the problem is positively traced to the power unit.

c) Generator maintenance concepts should be reviewed to ascertain compatibility for replacement of high failure rate modules. The inoperable modules could be removed and forwarded for depot level maintenance.

Appendix C

MEP Survey Results

List of Abbreviations

MTBF = Mean Time Between Failure
ENVIRON CONSTR = Environmental Constraints
OTH MOB FACTORS = Other Mobility Factors
IR = Infra Red
EMI = Electronmagnetic Interference
MTBO = Mean Time Between Overhauls

MEP SURVEY RESULTS

ANALYSIS GROUPING: -8 MAIN GENERATOR

NO. OF RESPONDENTS IN GROUP - 46

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
Q	OUTPUT QUALITY	80.91
I	TIME TO REPAIR	78.74
E	FUEL CONSUMPT	73.61
G	MTBF	73.09
N	ENVIRON CONSTR	68.69
H	LEVEL OF REPAIR	68.09
D	FUEL TYPE	67.61
C	OTH MOB FACTORS	66.83
O	OPERABILITY	64.00
P	START/STOP TIME	57.66
A	SIZE	55.46
B	WEIGHT	54.15
L	IR SIGNATURE	50.70
K	NOISE	50.17
F	USEFUL LIFE	47.26
M	EMI	44.76
J	MTBO	43.72

MEP SURVEY RESULTS

ANALYSIS GROUPING: MD3 MAIN GENERATOR

NO. OF RESPONDENTS IN GROUP - 47

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
Q	OUTPUT QUALITY	71.49
O	OPERABILITY	71.09
G	MTBF	67.66
I	TIME TO REPAIR	66.13
N	ENVIRON CONSTR	65.22
P	START/STOP TIME	63.07
E	FUEL CONSUMPT	62.98
H	LEVEL OF REPAIR	62.13
F	USEFUL LIFE	59.02
K	NOISE	57.98
J	MTBO	52.30
A	SIZE	47.34
D	FUEL TYPE	46.00
B	WEIGHT	45.77
C	OTH MOB FACTORS	43.68
M	EMI	29.91
L	IR SIGNATURE	27.15

MEP SURVEY RESULTS

ANALYSIS GROUPING: OTH MAIN GENERATOR

NO. OF RESPONDENTS IN GROUP - 52

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
O	OPERABILITY	73.91
Q	OUTPUT QUALITY	71.42
C	OTH MOB FACTORS	69.31
I	TIME TO REPAIR	65.63
A	SIZE	64.21
N	ENVIRON CONSTR	60.66
G	MTBF	60.18
E	FUEL CONSUMPT	59.02
B	WEIGHT	57.88
H	LEVEL OF REPAIR	55.78
D	FUEL TYPE	55.25
K	NOISE	55.02
P	START/STOP TIME	52.53
F	USEFUL LIFE	52.21
L	IR SIGNATURE	44.18
M	EMI	42.64
J	MTBO	39.12

MEP SURVEY RESULTS

ANALYSIS GROUPING: HOB MAIN GENERATOR

NO. OF RESPONDENTS IN GROUP - 20

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
Q	OUTPUT QUALITY	80.65
N	ENVIRON CONSTR	77.00
O	OPERABILITY	72.40
P	START/STOP TIME	67.85
G	MTBF	67.00
F	USEFUL LIFE	63.05
I	TIME TO REPAIR	62.90
E	FUEL CONSUMPT	62.75
K	NOISE	56.90
C	OTH MOB FACTORS	54.60
H	LEVEL OF REPAIR	53.95
B	WEIGHT	52.80
D	FUEL TYPE	51.20
J	MTBO	50.50
A	SIZE	48.15
E	EMI	26.25
L	IR SIGNATURE	25.75

MEP SURVEY RESULTS

ANALYSIS GROUPING: -60 MAIN GENERATOR

NO. OF RESPONDENTS IN GROUP - 70

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
Q	OUTPUT QUALITY	84.79
I	TIME TO REPAIR	70.90
O	OPERABILITY	69.13
E	FUEL CONSUMPT	65.17
G	MTBF	64.89
N	ENVIRON CONSTR	64.41
H	LEVEL OF REPAIR	60.83
K	NOISE	58.74
P	START/STOP TIME	55.30
B	WEIGHT	54.84
A	SIZE	53.30
F	USEFUL LIFE	52.23
D	FUEL TYPE	51.17
C	OTH MOB FACTORS	46.84
J	MTBO	46.04
M	EMI	32.89
L	IR SIGNATURE	25.36

MEP SURVEY RESULTS

ANALYSIS GROUPING: CRC/P*

NO. OF RESPONDENTS IN GROUP - 12

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
I	TIME TO REPAIR	93.75
G	MTBF	90.33
Q	OUTPUT QUALITY	81.75
H	LEVEL OF REPAIR	71.08
N	ENVIRON CONSTR	66.67
E	FUEL CONSUMPT	62.42
C	OTH MOB FACTORS	61.58
D	FUEL TYPE	61.25
P	START/STOP TIME	60.50
A	SIZE	54.42
O	OPERABILITY	53.58
B	WEIGHT	51.50
F	USEFUL LIFE	51.25
J	MTBO	51.25
K	NOISE	41.67
L	IR SIGNATURE	40.83
M	EMI	37.75

*COMMAND & CONTROL CENTER/POST

MEP SURVEY RESULTS

ANALYSIS GROUPING: FACP*

NO. OF RESPONDENTS IN GROUP - 26

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
Q	OUTPUT QUALITY	78.73
E	FUEL CONSUMPT	76.46
I	TIME TO REPAIR	72.54
G	MTBF	70.69
O	OPERABILITY	70.54
D	FUEL TYPE	69.08
C	OTH MOB FACTORS	68.77
N	ENVIRON CONSTR	65.96
H	LEVEL CONSTR	65.62
P	START/STOP TIME	57.50
B	WEIGHT	55.85
L	IR SIGNATURE	55.65
A	SIZE	54.38
K	NOISE	50.42
F	USEFUL LIFE	49.85
M	EMI	45.08
J	MTBO	43.04

*FORWARD AIR CONTROL PARTY

MEP SURVEY RESULTS

ANALYSIS GROUPING: TACP*

NO. OF RESPONDENTS IN GROUP - 13

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
O	OPERABILITY	89.92
K	NOISE	69.00
P	START/STOP TIME	65.54
C	OTH MOB FACTORS	65.00
A	SIZE	64.85
N	ENVIRON CONSTR	61.77
L	IR SIGNATURE	61.31
I	TIME TO REPAIR	58.77
M	EMI	58.69
D	FUEL TYPE	57.77
B	WEIGHT	57.46
Q	OUTPUT QUALITY	55.23
F	USEFUL LIFE	54.54
H	LEVEL OF REPAIR	54.54
E	FUEL CONSUMPT	54.46
G	MTBF	48.69
J	MTBO	43.77

*TACTICAL AIR CONTROL PARTY

MEP SURVEY RESULTS

ANALYSIS GROUPING: TACS ENLISTED

NO. OF RESPONDENTS IN GROUP - 5

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
O	OPERABILITY	81.00
C	OTH MOB FACTORS	68.00
F	USEFUL LIFE	53.00
N	ENVIRON CONSTR	53.00
I	TIME TO REPAIR	52.00
D	FUEL TYPE	49.00
P	START/STOP TIME	49.00
K	NOISE	46.00
L	IR SIGNATURE	46.00
H	LEVEL OF REPAIR	45.00
G	MTBF	41.80
A	SIZE	41.00
E	FUEL CONSUMPT	38.80
Q	OUTPUT QUALITY	38.40
E	EMI	34.40
J	MTBO	33.00
B	WEIGHT	24.00

MEP SURVEY RESULTS

ANALYSIS GROUPING: TACS NCO

NO. OF RESPONDENTS IN GROUP - 40

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
Q	OUTPUT QUALITY	77.20
I	TIME TO REPAIR	71.03
E	FUEL CONSUMPT	70.85
O	OPERABILITY	69.81
G	MTBF	69.43
C	OTH MOB FACTORS	66.57
N	ENVIRON CONSTR	65.58
D	FUEL TYPE	64.98
H	LEVEL OF REPAIR	61.58
A	SIZE	58.80
P	START/STOP TIME	58.47
B	WEIGHT	55.68
K	NOISE	51.55
L	IR SIGNATURE	49.40
F	USEFUL LIFE	45.88
M	EMI	45.18
J	MTBO	41.08

MEP SURVEY RESULTS

ANALYSIS GROUPING: TACS OFFICER*

NO. OF RESPONDENTS IN GROUP - 13

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
I	TIME TO REPAIR	84.77
Q	OUTPUT QUALITY	80.77
G	MTBF	77.92
E	FUEL CONSUMPT	75.00
D	FUEL TYPE	74.46
N	ENVIRON CONSTR	71.69
O	OPERABILITY	70.17
C	OTH MOB FACTORS	68.77
L	IR SIGNATURE	67.15
H	LEVEL OF REPAIR	65.00
K	NOISE	64.85
A	SIZE	63.54
B	WEIGHT	62.69
P	START/STOP TIME	61.67
F	USEFUL LIFE	55.00
E	EMI	54.92
J	MTBO	48.85

*TACTICAL AIR CONTROL SYSTEM

MEP SURVEY RESULTS

ANALYSIS GROUPING: CAMS*

NO. OF RESPONDENTS IN GROUP - 8

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
Q	OUTPUT QUALITY	85.00
G	MTBF	72.38
N	ENVIRON CONSTR	67.25
O	OPERABILITY	60.50
I	TIME TO REPAIR	60.25
K	NOISE	58.75
H	LEVEL OF REPAIR	56.25
E	FUEL CONSUMPT	54.38
B	WEIGHT	51.00
P	START/STOP TIME	50.50
A	SIZE	49.25
J	MTBO	43.13
C	OTH MOB FACTORS	41.00
D	FUEL TYPE	38.13
F	USEFUL LIFE	35.00
L	IR SIGNATURE	27.13
M	EMI	26.25

*CONSOLIDATED AIRCRAFT MAINTENANCE SQUADRON

MEP SURVEY RESULTS

ANALYSIS GROUPING: MMS*

NO. OF RESPONDENTS IN GROUP - 5

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
Q	OUTPUT QUALITY	91.00
K	NOISE	77.00
O	OPERABILITY	72.00
E	FUEL CONSUMPT	69.00
N	ENVIRON CONSTR	67.00
A	SIZE	56.00
B	WEIGHT	53.00
F	USEFUL LIFE	51.20
D	FUEL TYPE	50.60
P	START/STOP TIME	50.00
C	OTH MOB FACTORS	42.60
I	TIME TO REPAIR	42.20
G	MTBF	32.20
H	LEVEL OF REPAIR	30.20
J	MTBO	29.60
M	EMI	22.60
L	IR SIGNATURE	18.60

*MUNITIONS MAINTENANCE SQUADRON

MEP SURVEY RESULTS

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ANALYSIS GROUPING: AMS*

NO. OF RESPONDENTS IN GROUP - 10

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
Q	OUTPUT QUALITY	96.00
O	OPERABILITY	90.00
N	ENVIRON CONSTR	80.00
P	START/STOP TIME	67.50
K	NOISE	58.00
G	MTBF	52.00
F	USEFUL LIFE	46.50
I	TIME TO REPAIR	46.50
H	LEVEL OF REPAIR	45.50
M	EMI	40.00
L	IR SIGNATURE	38.50
D	FUEL TYPE	34.00
J	MTBO	34.00
E	FUEL CONSUMPT	33.50
C	OTH MOB FACTORS	29.00
B	WEIGHT	24.60
A	SIZE	23.50

*AVIONICS MAINTENANCE SQUADRON

MEP SURVEY RESULTS

ANALYSIS GROUPING: CRS*

NO. OF RESPONDENTS IN GROUP - 7

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
Q	OUTPUT QUALITY	96.43
K	NOISE	70.14
N	ENVIRON CONSTR	66.29
M	EMI	61.86
O	OPERABILITY	60.57
C	OTH MOB FACTORS	57.43
E	FUEL CONSUMPT	54.43
P	START/STOP TIME	54.29
G	MTBF	52.57
H	LEVEL OF REPAIR	49.43
B	WEIGHT	49.00
I	TIME TO REPAIR	46.43
A	SIZE	46.29
F	USEFUL LIFE	41.71
L	IR SIGNATURE	41.43
D	FUEL TYPE	37.00
J	MTBO	34.86

*COMPONENTS REPAIR SQUADRON

MEP SURVEY RESULTS

ANALYSIS GROUPING: AGS*

NO. OF RESPONDENTS IN GROUP - 4

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
A	SIZE	88.25
B	WEIGHT	77.25
C	OTH MOB FACTORS	70.50
O	OPERABILITY	59.75
K	NOISE	58.75
Q	OUTPUT QUALITY	57.50
P	START/STOP TIME	56.25
I	TIME TO REPAIR	50.00
N	ENVIRON CONSTR	48.75
E	FUEL CONSUMPT	45.00
H	LEVEL OF REPAIR	43.75
F	USEFUL LIFE	37.50
D	FUEL TYPE	36.25
G	MTBF	36.25
J	MTBO	30.00
L	IR SIGNATURE	27.25
M	EMI	22.00

*AIRCRAFT GENERATION SQUADRON

MEP SURVEY RESULTS

ANALYSIS GROUPING: EMS*

NO. OF RESPONDENTS IN GROUP - 23

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
Q	OUTPUT QUALITY	88.65
I	TIME TO REPAIR	87.65
H	LEVEL OF REPAIR	80.09
G	MTBF	76.65
E	FUEL CONSUMPT	74.70
F	USEFUL LIFE	72.48
O	OPERABILITY	70.83
D	FUEL TYPE	67.43
N	ENVIRON CONSTR	63.43
K	NOISE	58.26
J	MTBO	56.70
C	OTH MOB FACTORS	54.48
B	WEIGHT	54.43
P	START/STOP TIME	54.43
A	SIZE	53.52
M	EMI	40.39
L	IR SIGNATURE	35.52

*EQUIPMENT MAINTENANCE SQUADRON

MEP SURVEY RESULTS

ANALYSIS GROUPING: FMS*

NO. OF RESPONDENTS IN GROUP - 29

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
I	TIME TO REPAIR	83.00
G	MTBF	71.07
O	OPERABILITY	70.54
E	FUEL CONSUMPT	68.59
H	LEVEL OF REPAIR	67.66
Q	OUTPUT QUALITY	65.14
N	ENVIRON CONSTR	64.81
F	USEFUL LIFE	54.55
J	MTBO	54.31
A	SIZE	49.52
D	FUEL TYPE	49.52
K	NOISE	48.90
P	START/STOP TIME	46.96
B	WEIGHT	43.03
C	OTH MOB FACTORS	42.97
M	EMI	19.36
L	IR SIGNATURE	15.32

*FIELD MAINTENANCE SQUADRON

MEP SURVEY RESULTS

ANALYSIS GROUPING: BARE & BEEF

NO. OF RESPONDENTS IN GROUP - 6

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
A	SIZE	80.50
B	WEIGHT	70.17
C	OTH MOB FACTORS	69.17
N	ENVIRON CONSTR	69.00
E	FUEL CONSUMPT	68.83
O	OPERABILITY	67.33
Q	OUTPUT QUALITY	66.67
I	TIME TO REPAIR	61.67
H	LEVEL OF REPAIR	53.67
F	USEFUL LIFE	52.83
G	MTBF	50.00
K	NOISE	48.17
D	FUEL TYPE	46.67
P	START/STOP TIME	43.00
L	IR SIGNATURE	36.40
M	EMI	28.00
J	MTBO	27.00

MEP SURVEY RESULTS

ANALYSIS GROUPING: MOB

NO. OF RESPONDENTS IN GROUP - 8

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
O	OPERABILITY	93.75
I	TIME TO REPAIR	86.88
N	ENVIRON CONSTR	86.25
Q	OUTPUT QUALITY	85.63
H	LEVEL OF REPAIR	82.00
C	OTH MOB FACTORS	79.88
G	MTBF	70.50
P	START/STOP TIME	70.50
D	FUEL TYPE	68.88
E	FUEL CONSUMPT	62.38
A	SIZE	60.25
B	WEIGHT	59.13
M	EMI	59.00
L	IR SIGNATURE	52.50
F	USEFUL LIFE	51.63
K	NOISE	48.88
J	MTBO	40.63

MEP SURVEY RESULTS

ANALYSIS GROUPING: ATC*

NO. OF RESPONDENTS IN GROUP - 14

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
G	MTBF	81.07
O	OPERABILITY	78.57
H	LEVEL OF REPAIR	77.86
I	TIME TO REPAIR	75.00
Q	OUTPUT QUALITY	69.57
F	USEFUL LIFE	63.93
J	MTBO	58.21
E	FUEL CONSUMPT	55.71
N	ENVIRON CONSTR	54.29
P	START/STOP TIME	52.14
K	NOISE	46.79
A	SIZE	46.43
D	FUEL TYPE	45.36
B	WEIGHT	44.29
C	OTH MOB FACTORS	33.57
M	EMI	20.08
L	IR SIGNATURE	16.23

*AIR TRAINING COMMAND

MEP SURVEY RESULTS

ANALYSIS GROUPING: TACS*

NO. OF RESPONDENTS IN GROUP - 65

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
Q	OUTPUT QUALITY	74.71
I	TIME TO REPAIR	72.85
E	FUEL CONSUMPT	69.28
G	MTBF	69.08
O	OPERABILITY	68.42
C	OTH MOB FACTORS	66.57
D	FUEL TYPE	65.95
N	ENVIRON CONSTR	64.77
H	LEVEL OF REPAIR	61.89
A	SIZE	57.51
P	START/STOP TIME	57.47
K	NOISE	54.42
B	WEIGHT	54.03
L	IR SIGNATURE	52.85
F	USEFUL LIFE	48.77
M	EMI	46.97
J	MTBO	43.05

*TACTICAL AIR CONTROL SYSTEM

MEP SURVEY RESULTS

ANALYSIS GROUPING: AFCC*

NO. OF RESPONDENTS IN GROUP - 5

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
O	OPERABILITY	96.00
G	MTBF	86.80
Q	OUTPUT QUALITY	86.80
I	TIME TO REPAIR	85.20
N	ENVIRON CONSTR	84.00
P	START/STOP TIME	79.60
H	LEVEL OF REPAIR	76.20
C	OTH MOB FACTORS	75.80
M	EMI	68.40
D	FUEL TYPE	67.40
F	USEFUL LIFE	60.60
L	IR SIGNATURE	60.00
E	FUEL CONSUMPT	57.80
A	SIZE	54.40
B	WEIGHT	53.80
K	NOISE	46.20
J	MTBO	45.00

*AIR FORCE COMMUNICATIONS COMMAND

MEP SURVEY RESULTS

ANALYSIS GROUPING: AFSC*

NO. OF RESPONDENTS IN GROUP - 17

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
O	OPERABILITY	79.35
Q	OUTPUT QUALITY	72.18
I	TIME TO REPAIR	67.35
G	MTBF	64.29
P	START/STOP TIME	63.63
K	NOISE	62.65
N	ENVIRON CONSTR	60.29
E	FUEL CONSUMPT	57.94
H	LEVEL OF REPAIR	55.29
B	WEIGHT	54.29
F	USEFUL LIFE	54.06
A	SIZE	53.76
D	FUEL TYPE	41.76
J	MTBO	41.18
C	OTH MOB FACTORS	32.35
M	EMI	23.35
L	IR SIGNATURE	23.29

*AIR FORCE SYSTEMS COMMAND

MEP SURVEY RESULTS

ANALYSIS GROUPING: PACAF*

NO. OF RESPONDENTS IN GROUP - 20

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
Q	OUTPUT QUALITY	84.90
G	MTBF	73.30
I	TIME TO REPAIR	72.95
O	OPERABILITY	72.15
H	LEVEL OF REPAIR	64.00
N	ENVIRON CONSTR	63.45
A	SIZE	59.05
B	WEIGHT	58.80
E	FUEL CONSUMPT	57.75
C	OTH MOB FACTORS	5[illegible] 75
F	USEFUL LIFE	53.00
P	START/STOP TIME	52.20
J	MTBO	49.50
K	NOISE	49.00
D	FUEL TYPE	48.95
L	IR SIGNATURE	32.20
M	EMI	29.60

*PACIFIC AIR FORCES

MEP SURVEY RESULTS

ANALYSIS GROUPING: USAFE*

NO. OF RESPONDENTS IN GROUP - 27

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
Q	OUTPUT QUALITY	87.07
I	TIME TO REPAIR	67.93
N	ENVIRON CONSTR	64.85
H	LEVEL OF REPAIR	61.00
G	MTBF	58.81
K	NOISE	58.00
E	FUEL CONSUMPT	57.00
D	FUEL TYPE	55.70
C	OTH MOB FACTORS	54.63
O	OPERABILITY	53.81
A	SIZE	52.30
B	WEIGHT	52.15
P	START/STOP TIME	50.15
F	USEFUL LIFE	48.00
M	EMI	45.52
L	IR SIGNATURE	43.00
J	MTBO	39.30

*UNITED STATES AIR FORCES EUROPE

MEP SURVEY RESULTS

ANALYSIS GROUPING: MAC*

NO. OF RESPONDENTS IN GROUP - 26

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
Q	OUTPUT QUALITY	75.35
E	FUEL CONSUMPT	69.00
O	OPERABILITY	67.88
G	MTBF	66.56
N	ENVIRON CONSTR	64.50
C	OTH MOB FACTORS	63.54
K	NOISE	61.24
I	TIME TO REPAIR	60.88
P	START/STOP TIME	58.33
B	WEIGHT	57.42
F	USEFUL LIFE	57.38
A	SIZE	56.65
J	MTBO	49.38
D	FUEL TYPE	49.08
H	LEVEL OF REPAIR	48.44
L	IR SIGNATURE	21.32
M	EMI	20.20

*MILITARY AIRLIFT COMMAND

MEP SURVEY RESULTS

ANALYSIS GROUPING: SAC*

NO. OF RESPONDENTS IN GROUP - 45

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
Q	OUTPUT QUALITY	79.42
N	ENVIRON CONSTR	73.07
E	FUEL CONSUMPT	65.67
O	OPERABILITY	64.14
I	TIME TO REPAIR	61.64
P	START/STOP TIME	61.30
K	NOISE	58.98
G	MTBF	57.96
H	LEVEL OF REPAIR	50.44
F	USEFUL LIFE	47.33
D	FUEL TYPE	47.20
A	SIZE	47.04
B	WEIGHT	46.71
J	MTBO	45.53
C	OTH MOB FACTORS	44.27
M	EMI	35.07
L	IR SIGNATURE	26.47

*STRATEGIC AIR COMMAND

MEP SURVEY RESULTS

ANALYSIS GROUPING: TAC*

NO. OF RESPONDENTS IN GROUP - 76

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
Q	OUTPUT QUALITY	75.62
I	TIME TO REPAIR	75.05
O	OPERABILITY	72.79
E	FUEL CONSUMPT	71.05
G	MTBF	69.71
H	LEVEL OF REPAIR	66.84
C	OTH MOB FACTORS	66.74
N	ENVIRON CONSTR	63.86
D	FUEL TYPE	63.75
P	START/STOP TIME	58.45
A	SIZE	57.43
B	WEIGHT	55.17
K	NOISE	54.78
F	USEFUL LIFE	54.62
L	IR SIGNATURE	46.52
J	MTBO	45.38
M	EMI	44.87

*TACTICAL AIR COMMAND

MEP SURVEY RESULTS

ANALYSIS GROUPING: FLTLN NCO

NO. OF RESPONDENTS IN GROUP - 116

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
Q	OUTPUT QUALITY	78.61
I	TIME TO REPAIR	67.84
O	OPERABILITY	66.92
E	FUEL CONSUMPT	65.06
G	MTBF	64.40
N	ENVIRON CONSTR	63.77
H	LEVEL OF REPAIR	59.67
K	NOISE	58.76
P	START/STOP TIME	57.94
F	USEFUL LIFE	56.65
B	WEIGHT	52.60
A	SIZE	52.02
D	FUEL TYPE	49.38
C	OTH MOB FACTORS	48.10
J	MTBO	47.80
E	EMI	30.47
L	IR SIGNATURE	25.53

MEP SURVEY RESULTS

ANALYSIS GROUPING: FLTLN OFFICER

NO. OF RESPONDENTS IN GROUP - 13

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
Q	OUTPUT QUALITY	85.38
O	OPERABILITY	76.58
G	MTBF	72.77
I	TIME TO REPAIR	69.62
E	FUEL CONSUMPT	65.77
C	OTH MOB FACTORS	62.69
K	NOISE	62.69
N	ENVIRON CONSTR	60.75
H	LEVEL OF REPAIR	58.54
D	FUEL TYPE	57.54
P	START/STOP TIME	57.42
A	SIZE	55.08
B	WEIGHT	53.31
F	USEFUL LIFE	51.92
J	MTBO	51.54
M	EMI	38.46
L	IR SIGNATURE	32.92

MEP SURVEY RESULTS

ANALYSIS GROUPING: FLTLN*

NO. OF RESPONDENTS IN GROUP - 149

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
Q	OUTPUT QUALITY	78.95
O	OPERABILITY	68.94
I	TIME TO REPAIR	66.99
N	ENVIRON CONSTR	65.01
G	MTBF	64.99
E	FUEL CONSUMPT	63.50
H	LEVEL OF REPAIR	58.88
K	NOISE	58.13
P	START/STOP TIME	57.81
F	USEFUL LIFE	55.59
B	WEIGHT	51.54
A	SIZE	51.28
D	FUEL TYPE	48.83
C	OTH MOB FACTORS	48.75
J	MTBO	47.92
M	EMI	31.34
L	IR SIGNATURE	26.68

*FLIGHTLINE

MEP SURVEY RESULTS

ANALYSIS GROUPING: CIVILIAN

NO. OF RESPONDENTS IN GROUP - 13

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
Q	OUTPUT QUALITY	77.54
O	OPERABILITY	75.00
N	ENVIRON CONSTR	69.83
I	TIME TO REPAIR	63.46
G	MTBF	63.23
H	LEVEL OF REPAIR	60.23
E	FUEL CONSUMPT	53.46
P	START/STOP TIME	52.85
J	MTBO	47.15
F	USEFUL LIFE	45.38
A	SIZE	43.69
K	NOISE	43.69
C	OTH MOB FACTORS	39.77
B	WEIGHT	39.15
D	FUEL TYPE	38.54
M	EMI	28.23
L	IR SIGNATURE	23.15

MEP SURVEY RESULTS

ANALYSIS GROUPING: ENLISTED

NO. OF RESPONDENTS IN GROUP - 7

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
O	OPERABILITY	84.00
C	OTH MOB FACTORS	68.14
N	ENVIRON CONSTR	64.14
F	USEFUL LIFE	63.43
I	TIME TO REPAIR	62.00
D	FULE TYPE	60.86
P	START/STOP TIME	57.71
H	LEVEL OF REPAIR	57.14
Q	OUTPUT QUALITY	56.00
A	SIZE	48.57
G	MTBF	48.00
E	FUEL CONSUMPT	47.00
K	NOISE	44.86
L	IR SIGNATURE	40.71
J	MTBO	37.29
B	WEIGHT	36.14
M	EMI	34.57

MEP SURVEY RESULTS

ANALYSIS GROUPING: NCO

NO. OF RESPONDENTS IN GROUP - 173

PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
Q	OUTPUT QUALITY	78.52
I	TIME TO REPAIR	69.67
O	OPERABILITY	68.93
E	FUEL CONSUMPT	66.20
G	MTBF	65.87
N	ENVIRON CONSTR	64.95
H	LEVEL OF REPAIR	61.18
P	START/STOP TIME	58.11
K	NOISE	55.81
A	SIZE	55.12
C	OTH MOB FACTORS	54.90
B	WEIGHT	54.35
D	FUEL TYPE	53.80
F	USEFUL LIFE	53.52
J	MTBO	45.23
M	EMI	34.93
L	IR SIGNATURE	32.61

MEP SURVEY RESULTS

ANALYSIS GROUPING: OFFICER

NO. OF RESPONDENTS IN GROUP - 27

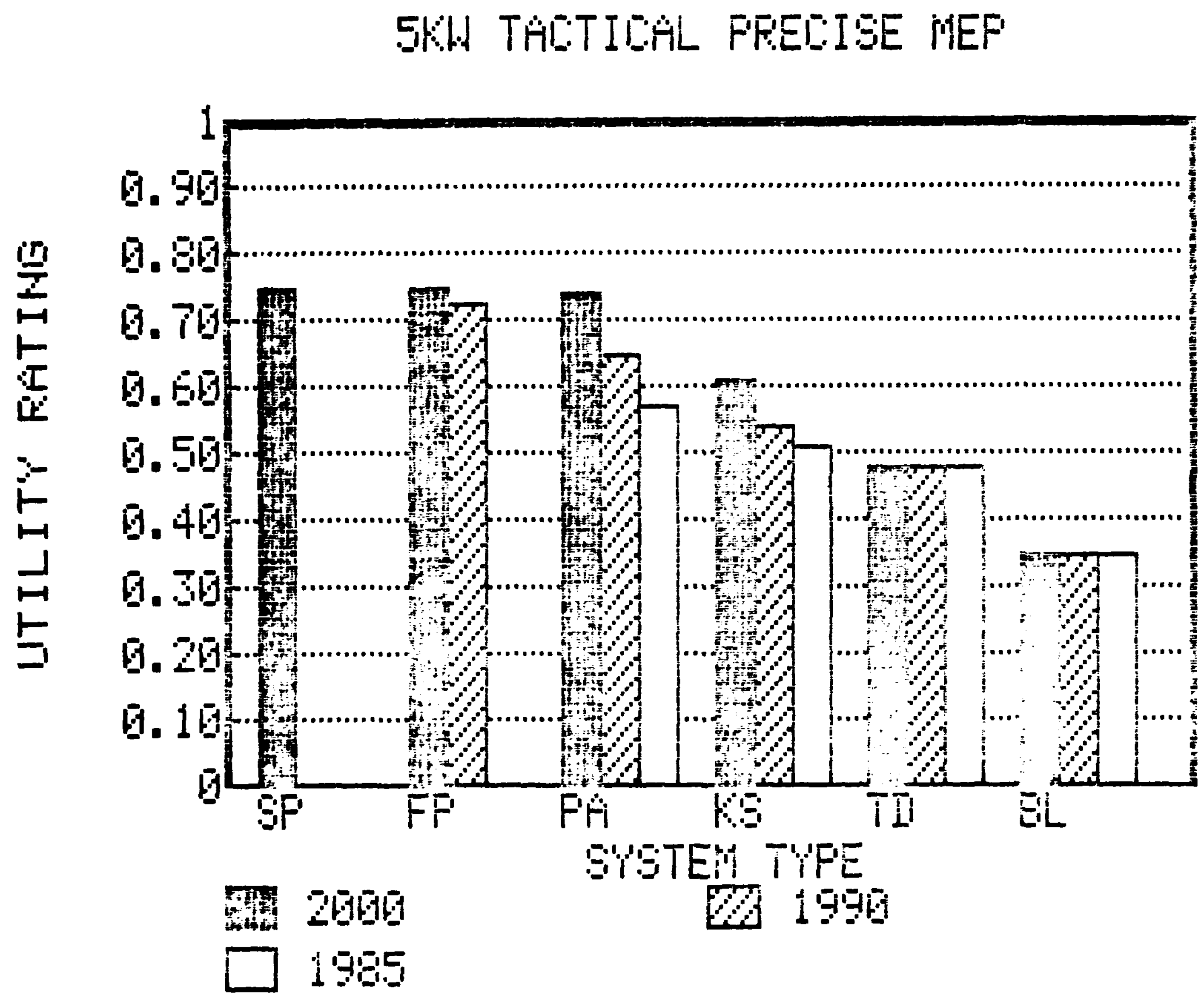
PAR CODE	PARAMETER DESCRIPTION	PARAMETER RATING
Q	OUTPUT QUALITY	81.85
I	TIME TO REPAIR	75.81
G	MTBF	72.93
O	OPERABILITY	72.44
E	FUEL CONSUMPT	69.63
N	ENVIRON CONSTR	67.69
C	OTH MOB FACTORS	66.63
K	NOISE	64.37
D	FUEL TYPE	64.30
A	SIZE	60.81
H	LEVEL OF REPAIR	60.59
B	WEIGHT	59.56
P	START/STOP TIME	58.76
F	USEFUL LIFE	54.07
L	IR SIGNATURE	48.56
J	MTBO	48.52
M	EMI	45.15

Appendix D

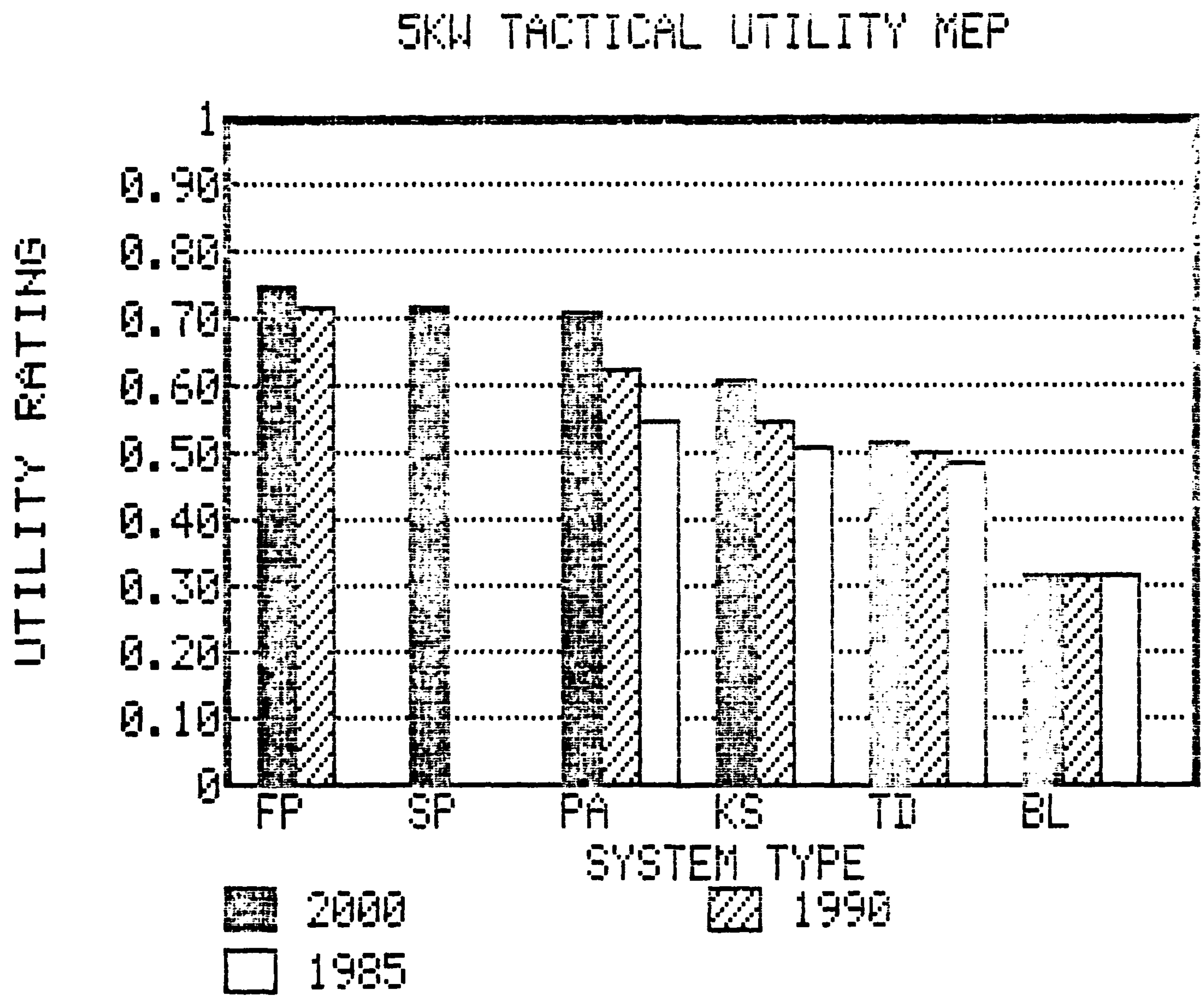
MEP System Utility Ratings

FOREWORD

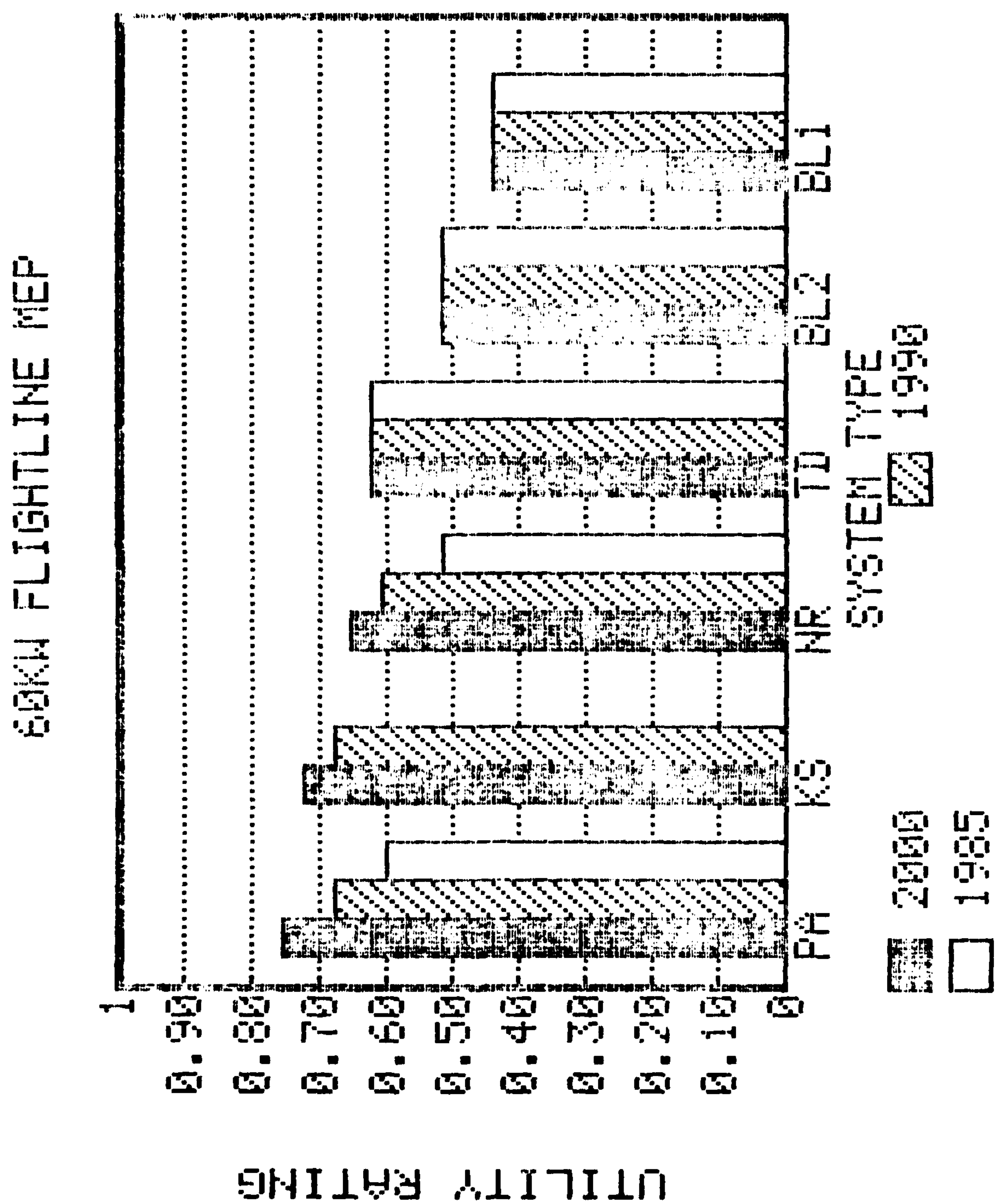
RO = Regenerative Open Cycle
CC = Closed Cycle
NR = Non-Regenerative
TC = Turbo-Compounded
TD = Turbo-Charged
AD = Adiabatic
FP = Free Piston
KS = Kinematic Stirling
PA = Phosphoric Acid
SP = Solid Polymer
PV = Flat Plate
AC = Actively Cooled
EC = Photoelectrochemical
WT = Vertical & Horizontal Wind Turbines

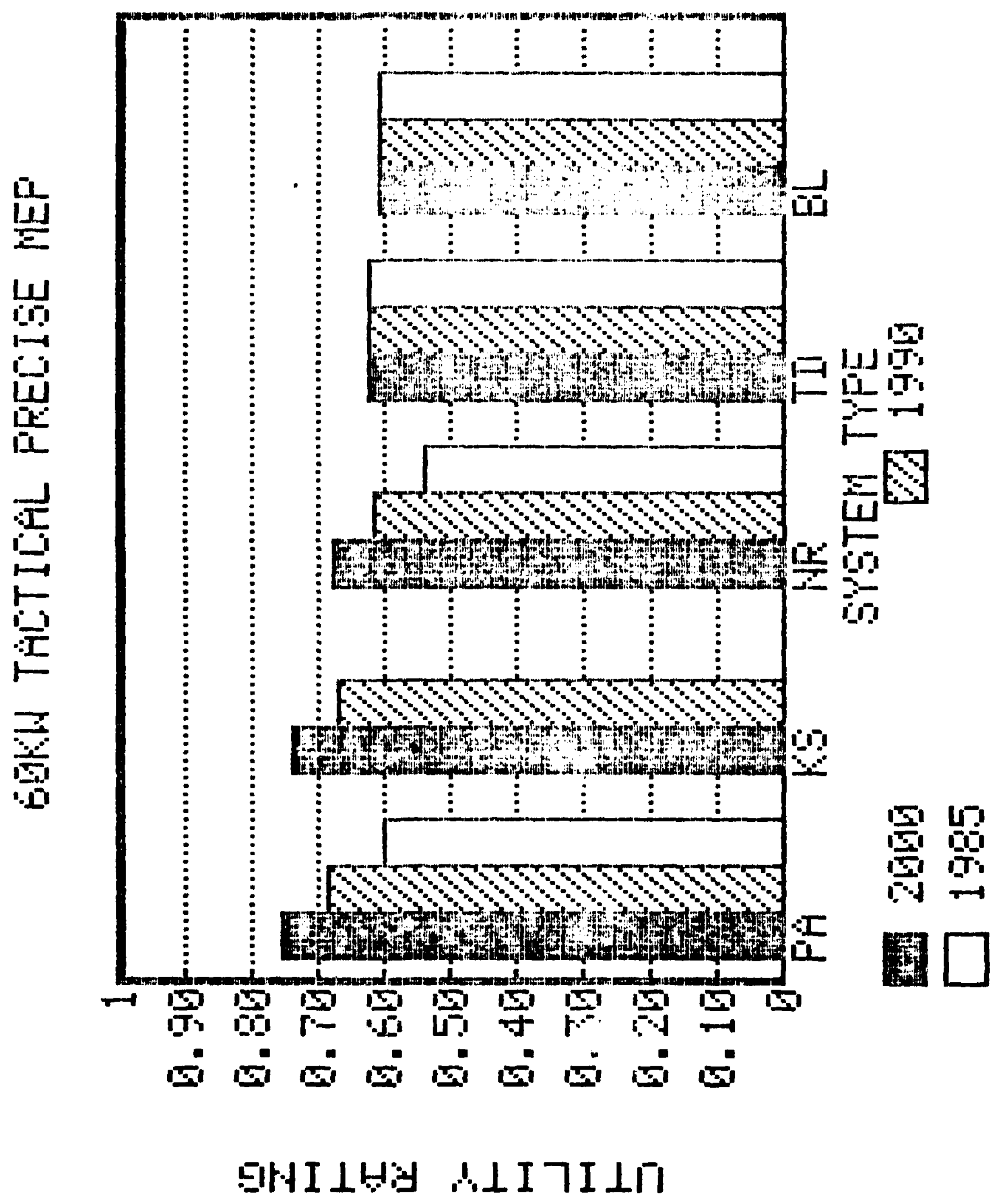


5KW TACTICAL PRECISE MEP
UTILITY RATING
1
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
SP
FP
PA
KS
TD
BL
SYSTEM TYPE
2000
1990
1985

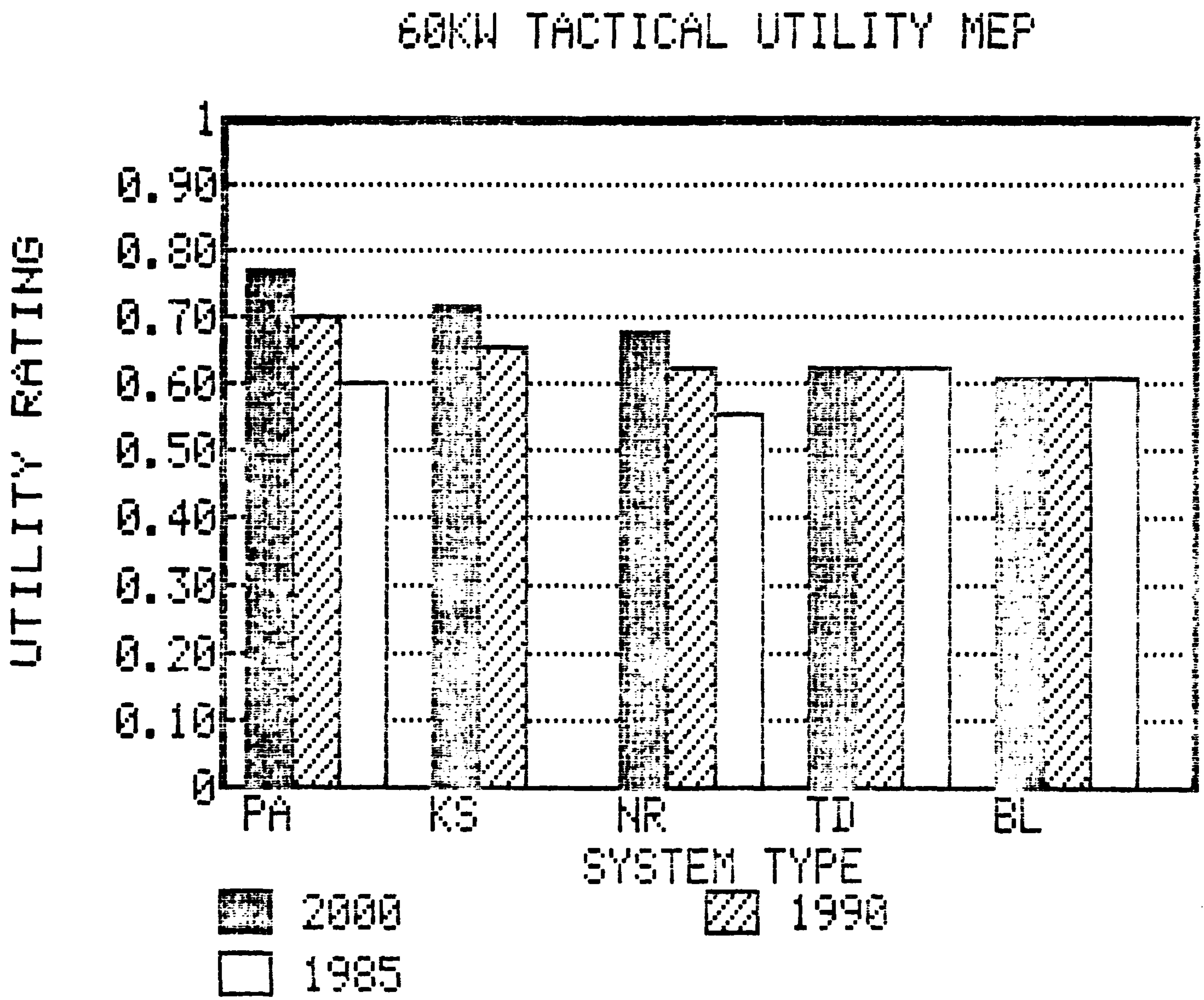


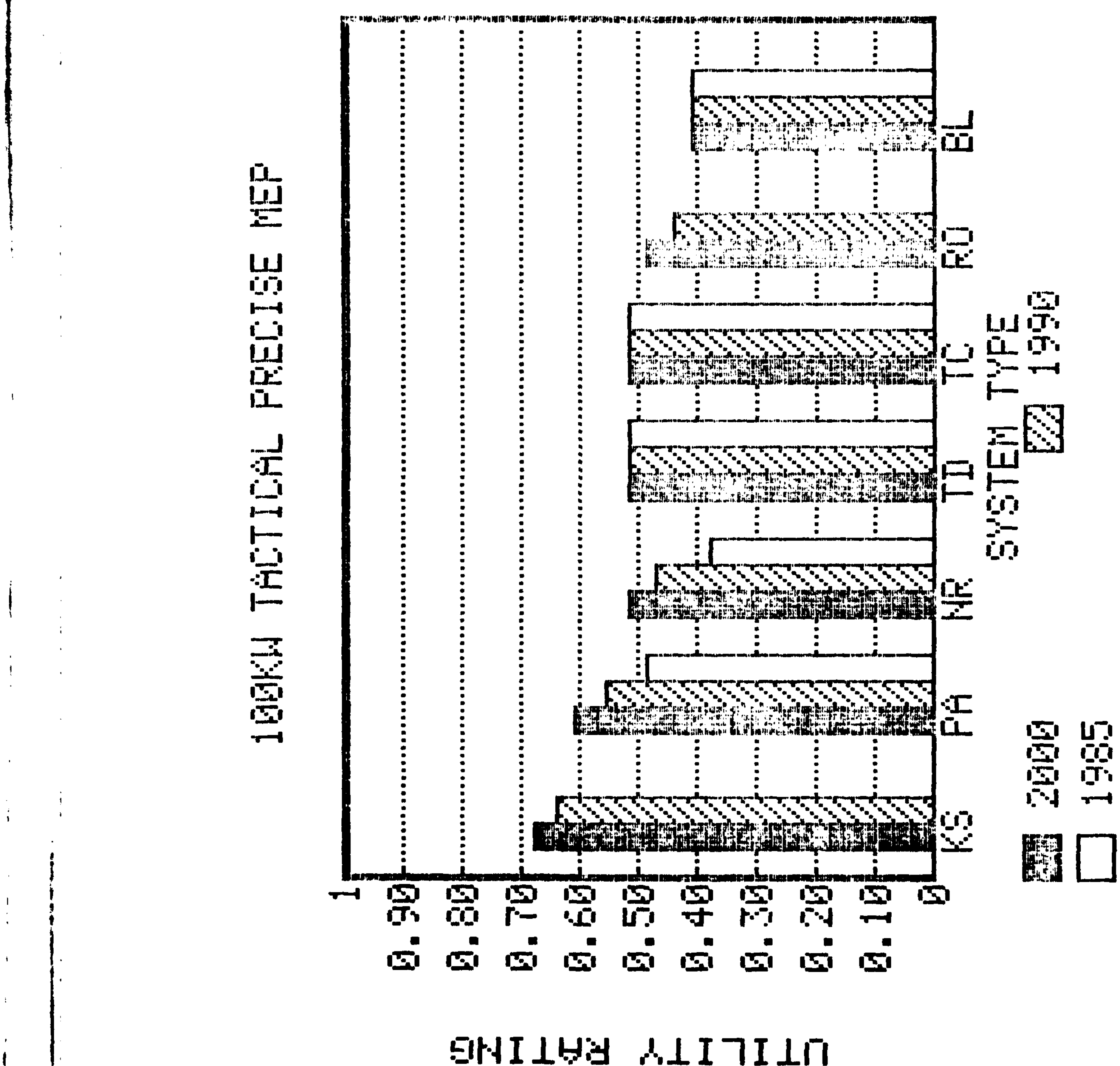
5KW TACTICAL UTILITY MEP
UTILITY RATING
1
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
FP
SP
PA
KS
TD
BL
SYSTEM TYPE
2000
1990
1985


60KW FLIGHTLINE MEP
UTILITY RATING
1
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
PA
KS
WR
TD
BL2
BL1
SYSTEM TYPE
2000
1985
1990

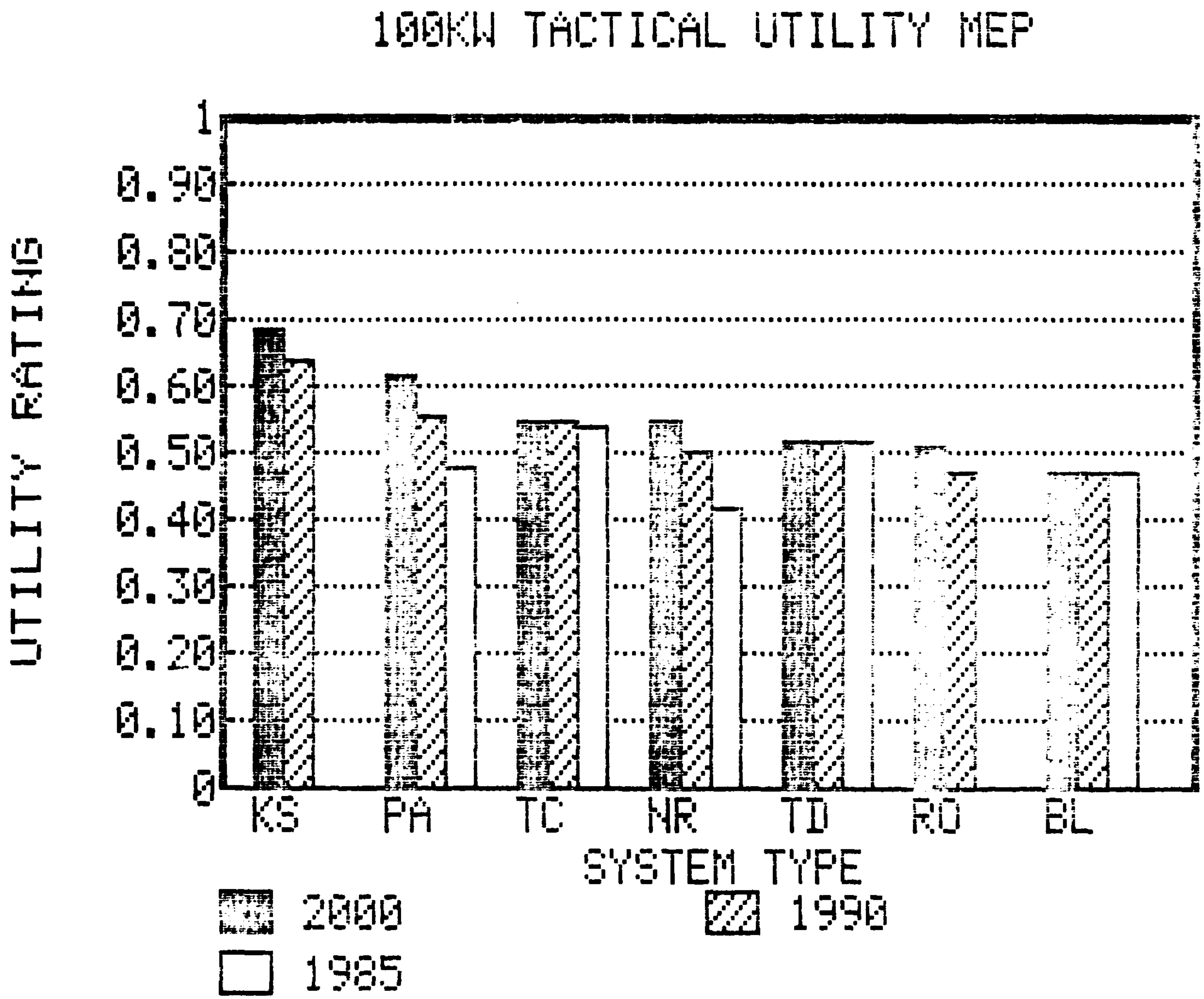


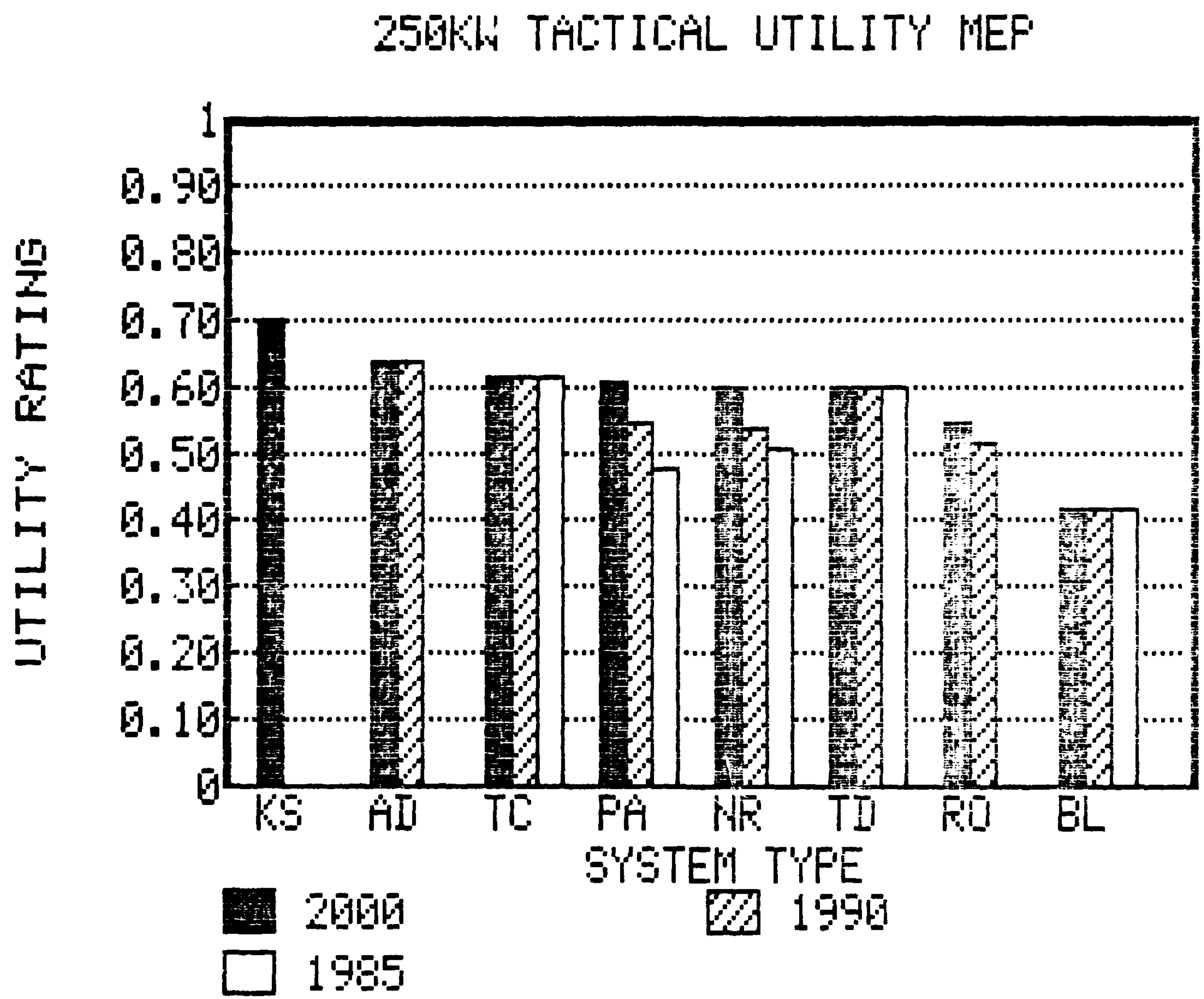
60KW TACTICAL PRECISE MEP
UTILITY RATING
1
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
PA
KS
NR
TD
BL
SYSTEM TYPE
2000
1990
1985


60KW TACTICAL UTILITY MEP
UTILITY RATING
1
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
PA
KS
NR
TD
BL
SYSTEM TYPE
2000
1990
1985

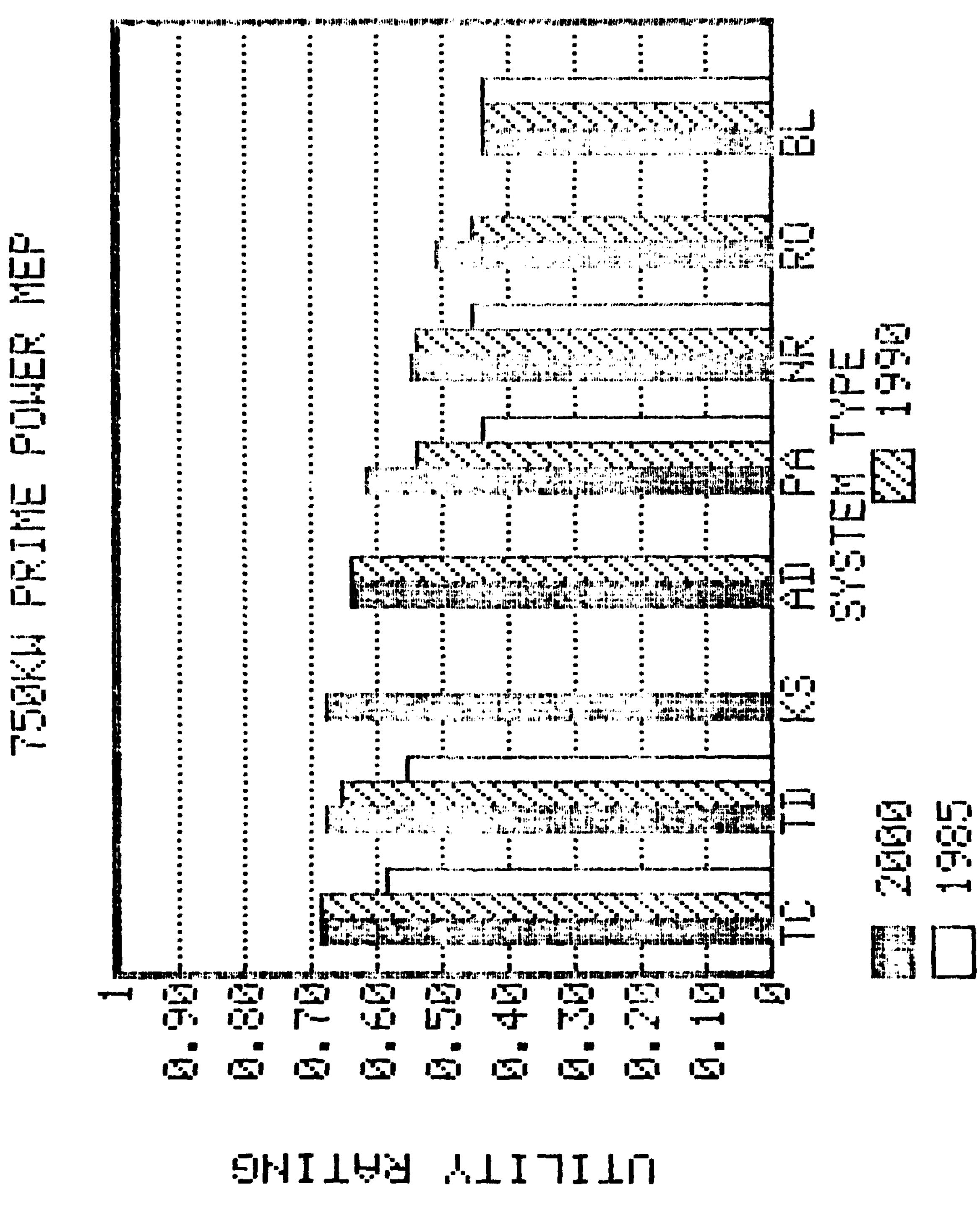


100KW TACTICAL PRECISE MEP
UTILITY RATINGS
SYSTEM TYPE
KS
PA
NR
TD
TC
RO
BL
1
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
2000
1985
1990


100KW TACTICAL UTILITY MEP
UTILITY RATING
1
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
KS
PA
TC
NR
TD
RO
BL
SYSTEM TYPE
2000
1990
1985



250KW TACTICAL UTILITY MEP
UTILITY RATING
1
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
KS
AD
TC
PA
NR
TD
RO
BL
SYSTEM TYPE
2000
1990
1985


750KW PRIME POWER MEP
UTILITY RATING
1
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
TC
TD
KS
AD
PA
MR
RO
BL
SYSTEM TYPE
2000
1990
1985

Appendix E

MEP Life Cycle Costs

20-YEAR LIFE CYCLE COSTS IN 1980$

5 kW POWER LEVEL

YEAR	GENERATOR TYPE	ACQUISITION COST	LIFE TIME	ANNUAL O&M COST	ANNUAL FUEL COST	AVG ANNUAL LCC	AVG ANNUAL LCC (1/8 OPERATING CYCLE)
2000	DIESEL-TCHG	5,300	20	133	3,730	4,128	864
2000	STIRLING-FP	4,500	20	50	3,219	3,494	677
2000	STIRLING-KN	9,000	20	300	3,506	4,256	1,188
2000	FUEL CELL-PA	3,500	10	350	2,880	3,580	1,060
2000	FUEL CELL-SP	25,000	10	2,500	2,370	7,370	5,296
2000	P/V-FP	692,000	20	44,000	0	78,600	9,825
2000	P/V-AC	1,010,000	20	63,100	0	113,600	14,200
2000	P/V-PC	692,000	20	44,000	0	78,600	9,825
2000	WIND-VA	66,700	20	3,830	0	7,165	896
2000	WIND-HA	66,700	20	3,830	0	7,165	896
2000	BASELINE	8,000	20	200	6,091	6,691	1,361
1990	DIESEL-TCHG	5,300	20	133	3,730	4,128	864
1990	STIRLING-FP	4,500	12	50	3,864	4,289	908
1990	STIRLING-KN	9,000	6	300	4,631	6,431	2,379
1990	FUEL CELL-PA	13,000	10	1,300	3,060	5,660	2,983
1990	FUEL CELL-SP	0	0	0	0	0	0
1990	P/V-FP	692,000	20	44,000	0	78,600	9,825
1990	P/V-AC	1,010,000	20	63,100	0	113,600	14,200
1990	P/V-PC	0	0	0	0	0	0
1990	WIND-VA	66,700	20	3,830	0	7,165	896
1990	WIND-HA	66,700	20	3,830	0	7,165	896
1990	BASELINE	8,000	20	200	6,091	6,691	1,361
1985	DIESEL-TCHG	4,820	20	121	3,920	4,282	852
1985	STIRLING-FP	0	0	0	0	0	0
1985	STIRLING-KN	9,000	3	300	5,795	9,095	4,024
1985	FUEL CELL-PA	25,000	10	2,500	3,330	8,330	5,416
1985	FUEL CELL-SP	0	0	0	0	0	0
1985	P/V-FP	815,000	20	51,400	0	92,150	11,519
1985	P/V-AC	1,190,000	20	73,900	0	133,400	16,675
1985	P/V-PC	0	0	0	0	0	0
1985	WIND-VA	70,400	20	3,910	0	7.430	929
1985	WIND-HA	70,400	20	3,910	0	7,430	929
1985	BASELINE	8,000	20	200	6,091	6,691	1,361

20-YEAR LIFE CYCLE COSTS IN 1980$

60 kW POWER LEVEL

YEAR	GENERATOR TYPE	ACQUISITION COST	LIFE TIME	ANNUAL O&M COST	ANNUAL FUEL COST	AVG ANNUAL LCC	AVG ANNUAL LCC (1/8 OPERATING CYCLE)
2000	TURBINE-NROC	50,000	11	1,600	126,000	132,145	21,895
2000	DIESEL-TCHG	111,000	20	1,210	39,300	46,060	11,673
2000	STIRLING-KN	30,000	20	2,970	36,620	41,090	9,048
2000	FUEL CELL-PA	42,000	10	4,200	33,300	41,700	12,563
2000	P/V-FP	8,320,000	20	529,000	0	945,000	118,000
2000	P/V-AC	12,000,000	20	750,000	0	1,350,000	168,000
2000	WIND-VA	437,000	20	38,800	0	60,650	7,581
2000	WIND-HA	437,000	20	38,800	0	60,650	7,581
2000	BASELINE-TP	95,325	11	3,050	172,747	184,463	33,309
2000	BASELINE-TU	23,418	20	255	64,123	65,549	9,441
2000	BASELINE-FL1	83,000	11	2,656	375,979	386,180	57,199
2000	BASELINE-FL2	23,403	20	255	71,604	73,029	10,376
1990	TURBINE-NROC	50,000	11	1,600	153,000	159,145	25,270
1990	DIESEL-TCHG	111,000	20	1,210	39,300	46,060	11,673
1990	STIRLING-KN	30,000	6	2,970	43,440	51,410	13,400
1990	FUEL CELL-PA	150,000	10	15,000	35,100	65,100	34,388
1990	P/V-FP	8,320,000	20	529,000	0	945,000	108,000
1990	P/V-AC	12,000,000	20	750,000	0	1,350,000	168,000
1990	WIND-VA	437,000	20	38,800	0	60,650	7,581
1990	WIND-HA	437,000	20	38,800	0	60,650	7,581
1990	BASELINE-TP	95,325	11	3,050	172,747	184,463	33,309
1990	BASELINE-TU	23,418	20	255	64,123	65,549	9,441
1990	BASELINE-FL1	83,000	11	2,656	375,979	386,180	57,199
1990	BASELINE-FL2	23,403	20	255	71,604	73,029	10,376
1985	TURBINE-NROC	50,000	11	1,600	153,000	159,145	25,270
1985	DIESEL-TCHG	101,000	20	1,100	41,300	47,450	11,313
1985	STIRLING-KN	0	0	0	0	0	0
1985	FUEL CELL-PA	300,000	10	30,000	40,000	100,000	65,000
1985	P/V-FP	9,810,000	20	619,000	0	1,109,500	139,000
1985	P/V-AC	14,300,000	20	888,000	0	1,603,000	200,000
1985	WIND-VA	0	0	0	0	0	0
1985	WIND-HA	462,000	20	39,400	0	62,500	7,812
1985	BASELINE-TP	95,325	11	3,050	172,747	184,463	33,309
1985	BASELINE-TU	23,418	20	255	64,123	65,549	9,441
1985	BASELINE-FL1	83,000	11	2,656	375,979	386,180	57,199
1985	BASELINE-FL2	23,403	20	255	71,604	73,029	10,376

20-YEAR LIFE CYCLE COSTS IN 1980$

100 kW POWER LEVEL

YEAR	GENERATOR TYPE	ACQUISITION COST	LIFE TIME	ANNUAL O&M COST	ANNUAL FUEL COST	AVG ANNUAL LCC	AVG ANNUAL LCC (1/8 OPERATING CYCLE)
2000	TURBINE-ROC	70,000	11	3,180	58,050	67,680	16,800
2000	TURBINE-NROC	60,000	11	2,600	135,000	143,055	24,930
2000	DIESEL-TCMP	391,000	20	3,580	54,300	77,430	29,918
2000	DIESEL-TCHG	244,000	20	2,030	64,100	78,330	22,243
2000	STIRLING-KN	50,000	20	4,530	60,740	67,770	14,623
2000	FUEL CELL-PA	70,000	10	7,000	51,300	65,300	20,413
2000	P/V-FP	13,700,000	20	872,000	0	1,557,000	195,000
2000	P/V-AC	19,900,000	20	1,240,000	0	2,235,000	279,000
2000	WIND-VA	649,000	20	62,900	0	95,350	11,900
2000	WIND-HA	649,000	20	62,900	0	95,350	11,900
2000	BASELINE-TU	26,000	20	260	90,841	92,401	12,915
1990	TURBINE-ROC	70,000	11	3,180	58,050	67,680	16,800
1990	TURBINE-NROC	60,000	11	2,600	144,000	152,055	26,055
1990	DIESEL-TCMP	391,000	20	3,580	54,300	77,430	29,918
1990	DIESEL-TCHG	244,000	20	2,030	64,100	78,330	22,243
1990	STIRLING-KN	50,000	6	4,530	72,150	85,013	21,882
1990	FUEL CELL-PA	250,000	10	25,000	57,600	107,600	57,200
1990	P/V-FP	13,700,000	20	872,000	0	1,557,000	195,000
1990	P/V-AC	19,900,000	20	1,240,000	0	2,235,000	279,000
1990	WIND-VA	0	0	0	0	0	0
1990	WIND-HA	649,000	20	62,900	0	95,350	11,900
1990	BASELINE-TU	26,000	20	260	90,841	92,401	12,915
1985	TURBINE-ROC	0	0	0	0	0	0
1985	TURBINE-NROC	60,000	11	2,600	144,000	152,055	26,055
1985	DIESEL-TCMP	355,000	20	3,250	57,000	78,000	28,125
1985	STIRLING-KN	0	0	0	0	0	0
1985	FUEL CELL-PA	500,000	10	50,000	61,200	161,200	107,650
1985	P/V-FP	16,300,000	20	1,030,000	0	1,845,000	230,000
1985	P/V-AC	23,800,000	20	1,480,000	0	2,670,000	333,000
1985	WIND-VA	0	0	0	0	0	0
1985	WIND-HA	717,000	20	64,800	0	100,650	12,600
1985	BASELINE-TU	26,000	20	260	90,841	92,401	12,915
1985	BASELINE-TP	64,800	20	648	106,872	110,760	17,247

20-YEAR LIFE CYCLE COSTS IN 1980$

250 kW POWER LEVEL

YEAR	GENERATOR TYPE	ACQUISITION COST	LIFE TIME	ANNUAL O&M COST	ANNUAL FUEL COST	AVG ANNUAL LCC	AVG ANNUAL LCC (1/8 OPERATING CYCLE)
2000	TURBINE-ROC	210,000	11	5,800	148,600	173,500	43,466
2000	TURBINE-NROC	200,000	11	5,500	303,400	327,000	61,607
2000	DIESEL-TCMP	845,000	20	6,410	136,000	184,660	65,660
2000	DIESEL-TCHG	528,000	20	4,010	153,000	183,410	49,535
2000	DIESEL-ADBT	761,000	20	5,780	50,200	94,130	50,118
2000	STIRLING-KN	125,000	20	11,250	152,100	169,600	36,513
2000	FUEL CELL-PA	180,000	10	18,000	126,000	162,000	51,750
2000	P/V-FP	34,100,000	20	2,170,000	0	3,875,000	484,000
2000	P/V-AC	49,800,000	20	3,110,000	0	5,600,000	700,000
2000	WIND-HA	1,550,000	20	156,000	0	233,500	29,200
2000	BASELINE	61,080	20	611	213,744	217,409	30,383
1990	TURBINE-ROC	210,000	11	5,800	148,600	173,500	43,466
1990	TURBINE-NROC	200,000	11	5,500	341,000	365,000	66,307
1990	DIESEL-TCMP	845,000	20	6,420	136,000	184,670	65,670
1990	DIESEL-TCHG	528,000	20	4,010	153,000	183,410	49,535
1990	DIESEL-ADBT	761,000	20	5,780	50,300	94,130	50,118
1990	STIRLING-KN	0	0	0	0	0	0
1990	FUEL CELL-P	500,000	10	50,000	144,000	244,000	118,000
1990	P/V-FP	34,100,000	20	2,170,000	0	3,875,000	484,000
1990	P/V-AC	49,800,000	20	3,110,000	0	5,600,000	700,000
1990	WIND-HA	1,550,000	20	156,000	0	233,500	24,200
1990	BASELINE	61,080	20	611	213,744	217,409	30,383
1985	TURBINE-ROC	0	0	0	0	0	0
1985	TURBINE-NROC	200,000	11	5,500	341,000	365,000	66,307
1985	DIESEL-TCMP	768,000	20	5,840	142,000	186,240	61,990
1985	DIESEL-TCHG	480,000	20	3,650	161,000	188,650	47,775
1985	DIESEL-ADBT	0	0	0	0	0	0
1985	STIRLING-KN	0	0	0	0	0	0
1985	FUEL CELL-PA	1,000,000	10	100,000	153,000	353,000	219,125
1985	P/V-FP	40,800,000	20	2,570,000	0	4,610,000	576,000
1985	PV/-AC	59,500,000	20	3,700,000	0	6,675,000	834,000
1985	WIND-HA	1,630,000	20	160,000	0	241,500	30,200
1985	BASELINE	61,080	20	611	213,744	217,409	30,383

20-YEAR LIFE CYCLE COSTS IN 1980$

750 kW POWER LEVEL

YEAR	GENERATOR TYPE	ACQUISITION COST	LIFE TIME	ANNUAL O&M COST	ANNUAL FUEL COST	AVG ANNUAL LCC	AVG ANNUAL LCC (1/8 OPERATING CYCLE)
2000	TURBINE-ROC	420,000	11	13,000	433,000	484,000	105,300
2000	TURBINE-NROC	400,000	11	15,000	720,000	771,000	141,000
2000	DIESEL-TCMP	2,060,000	20	20,300	372,000	495,300	169,800
2000	DIESEL-TCHG	1,290,000	20	12,700	439,000	516,200	132,075
2000	DIESEL-ADBT	1,830,000	20	18,000	241,000	350,500	139,625
2000	STIRLING-KN	331,000	20	33,750	453,200	492,500	106,400
2000	FUEL CELL-PA	530,000	10	53,000	387,000	493,000	154,375
2000	P/V-FP	104,000,000	20	6,620,000	0	11,820,000	1,478,000
2000	P/V-AC	150,000,000	20	9,380,000	0	16,880,000	2,110,000
2000	WIND-HA	4,650,000	20	467,000	0	699,500	87,400
2000	BASELINE	450,000	11	2,350	587,796	631,055	116,734
1990	TURBINE-ROC	420,000	11	13,000	433,000	484,000	105,300
1990	TURBINE-NROC	400,000	11	15,000	720,000	771,000	141,000
1990	DIESEL-TCMP	2,060,000	20	20,300	372,000	495,300	169,800
1990	DIESEL-TCHG	1,290,000	20	12,700	439,000	516,200	132,075
1990	DIESEL-ADBT	1,830,000	20	18,000	241,000	350,500	139,625
1990	STIRLING-KN	0	0	0	0	0	0
1990	FUEL CELL-PA	1,500,000	10	150,000	432,000	732,000	354,000
1990	P/V-FP	104,000,000	20	6,620,000	0	11,820,000	1,478,000
1990	P/V-AC	150,000,000	20	9,380,000	0	16,880,000	2,110,000
1990	WIND-HA	4,650,000	20	467,000	0	699,500	87,400
1990	BASELINE	450,000	11	2,350	587,796	631,055	116,734
1985	TURBINE-ROC	0	0	0	0	0	0
1985	TURBINE-NROC	400,000	11	15,000	774,000	886,000	208,750
1985	DIESEL-TCMP	1,870,000	20	18,500	390,000	502,000	160,750
1985	DIESEL-TCHG	1,170,000	20	11,600	460,000	530,100	127,600
1985	DIESEL-ADBT	0	0	0	0	0	0
1985	STIRLING-KN	0	0	0	0	0	0
1985	FUEL CELL-PA	3,000,000	10	300,000	459,000	1,059,000	657,375
1985	P/V-FP	0	0	0	0	0	0
1985	P/V-AC	0	0	0	0	0	0
1985	WIND-HA	4,890,000	20	479,000	0	723,500	90,438
1985	BASELINE	450,000	11	2,350	587,796	631,055	116,734

20-YEAR LIFE CYCLE COSTS IN 1980$

Facilities' Systems Using Natural Gas or Residual Fuel

YEAR	GENERATOR TYPE	ACQUISITION COST	LIFE TIME	ANNUAL O&M COST	ANNUAL FUEL COST	AVG ANNUAL LCC	AVG ANNUAL LCC (1/8 OPERATING CYCLE)
			250 kW Power Level				
2000	TURBINE-ROC	210,000	11	5,800	43,200	68,091	30,291
2000	TURBINE-NROC	200,000	11	5,500	88,200	111,882	34,707
2000	FUEL CELL-PA	180,000	10	18,000	42,000	78,000	41,250
1990	TURBINE-ROC	210,000	11	5,800	43,000	68,091	30,291
1990	TURBINE-NROC	200,000	11	5,500	99,000	122,682	36,057
1990	FUEL CELL-PA	500,000	10	50,000	47,000	178,000	105,875
1985	TURBINE-ROC	0	0	0	0	0	0
1985	TURBINE-NROC	200,000	11	5,500	99,000	122,682	36,057
1985	FUEL CELL-PA	1,000,000	10	100,000	49,000	249,000	206,125
			750 kW Power Level				
2000	TURBINE-ROC	420,000	11	13,000	126,000	177,182	66,932
2000	TURBINE-NROC	400,000	11	15,000	207,000	258,364	77,239
2000	STIRLING-KN*	331,000	20	33,750	308,231	358,531	88,829
2000	FUEL CELL-PA	530,000	10	53,000	120,000	226,000	121,000
1990	TURBINE-ROC	420,000	11	13,000	126,000	177,182	66,932
1990	TURBINE-NROC	400,000	11	15,000	225,000	276,364	79,489
1990	FUEL CELL-PA	1,500,000	10	150,000	140,000	440,000	317,500
1985	TURBINE-ROC	0	0	0	0	0	0
1985	TURBINE-NROC	400,000	11	15,000	225,000	276,364	79,489
1985	FUEL CELL-PA	3,000,000	10	300,000	150,000	750,000	618,750

*Residual Fuel

All Others - Natural Gas

20-YEAR LIFE CYCLE COSTS IN 1980$

5000 kW POWER LEVEL

YEAR	GENERATOR TYPE	ACQUISITION COST	LIFE TIME	ANNUAL O&M COST	ANNUAL FUEL COST	AVG ANNUAL LCC	AVG ANNUAL LCC (1/8 OPERATING CYCLE)
2000	TURBINE-ROC*	1,900,000	11	81,100	816,000	1,063,727	355,077
2000	TURBINE-CC+	2,000,000	11	81,000	1,890,000	2,152,818	499,068
2000	TURBINE-NROC*	1,800,000	11	77,000	1,170,000	1,540,636	403,136
2000	DIESEL-TCMP	8,270,000	20	324,000	2,300,000	3,037,500	1,025,000
2000	DIESEL-TCHG	5,170,000	20	203,000	2,720,000	3,181,500	801,500
2000	DIESEL-ADBT	7,450,000	20	292,000	1,120,000	1,784,500	804,500
2000	FUEL CELL-PA*	3,500,000	10	350,000	747,000	1,447,000	793,375
2000	P/V-FP	683,000,000	20	43,500,000	0	77,650,000	9,706,000
2000	BASELINE	0	20	0	2,190,000	2,190,000	273,750
1990	TURBINE-ROC*	1,900,000	11	81,100	816,000	1,063,727	355,077
1990	TURBINE-CC+	2,000,000	11	81,000	2,340,000	2,602,818	555,318
1990	TURBINE-NROC*	1,800,000	11	77,000	1,170,000	1,540,636	403,136
1990	DIESEL-TCMP	8,270,000	20	324,000	2,300,000	3,037,500	1,025,000
1990	DIESEL-TCHG	5,170,000	20	203,000	2,720,000	3,181,500	801,500
1990	DIESEL-ADBT	7,450,000	20	292,000	1,120,000	1,136,500	804,000
1990	FUEL CELL-PA*	10,000,000	10	1,000,000	837,000	2,837,000	2,105,000
1990	P/V-FP	0	0	0	0	0	0
1990	BASELINE	0	20	0	2,190,000	2,190,000	273,750
1985	TURBINE-ROC*	1,900,000	11	81,100	816,000	1,063,727	355,077
1985	TURBINE-CC+	2,000,000	11	81,100	2,340,000	2,602,818	555,318
1985	TURBINE-NROC*	1,800,000	11	77,000	1,260,000	1,640,636	415,636
1985	DIESEL-TCMP	7,520,000	20	295,000	2,410,000	3,081,000	972,250
1985	DIESEL-TCHG	4,700,000	20	184,000	2,840,000	3,259,000	774,000
1985	DIESEL-ADBT	0	0	0	0	0	0
1985	FUEL CELL-PA*	20,000,000	10	2,000,000	882,000	4,882,000	4,120,000
1985	P/V-FP	0	0	0	0	0	0
1985	BASELINE	0	20	0	2,190,000	2,190,000	273,750

* = Natural Gas Fuel
+ = Residual Fuel
Others Use Diesel Fuel

Appendix F

Research Team Reports on R&D Requirements

F-1

Mechanical Technology Inc.

Report on Stirling Cycle and Gas Turbine Engine

2.0 STIRLING ENGINE R&D REQUIREMENTS

Objective

This report is to identify the research and development (R&D) requirements necessary to overcome deficiencies in Stirling engine technologies so that commercial availability will be possible.

Background

Stirling engines are not currently available on a commercial basis. Significant development efforts are underway, however, to advance the state-of-the-art so that units can be commercialized. As noted in Reference 1, a number of contractors are currently engaged in the development of Stirling engines. Major activity centers around a few well-focused programs as listed in Table 1. It is these program which formulate the basis for the work accomplished under Task 1 in projecting the attributes of future Stirling engines. The key assumptions, then, in projecting Stirling engine attributes is that these programs will continue to their technical conclusion. Without this, *at a minimum*, there would be no rationale for expecting any commercialization of Stirling engine whatsoever.

The comments put forth in this task, then, consider R&D requirements over and above the ongoing efforts. Beyond this, two separate perspectives have been considered for identifying R&D requirements:

1. R&D necessary to achieve the parametric values listed in the Task 1.0 report; and,

2. high-risk R&D to accelerate technical progress or to increase system effectiveness beyond those values.

Recommendations

1. Modularity

   a. No R&D recommended.

2. Availability

   a. FPSE (Required R&D)
   Based on current development programs, Free-Piston Stirling Engines (FPSE) will be developed in frame sizes of 1K and 3 kW. There is speculation that some private funding of a 10-kW unit is proceeding, but this has not been confirmed through public disclosure. To achieve availability of units up to 30 kW will require substantial efforts to upsize from current designs. Technical challenges will include heat exchanger design and system vibration problems.

   b. FPSE (Advanced R&D)
   High-risk development could lead to the availability of FPSE's with rated capacity in excess of 30 kW by the 2000 time frame.

   c. Kinematic (Required R&D)
   Current development activities are limited to capacity sizes below 100 kW. R&D programs will need to be put in place to achieve higher power sizes by the year 2000. Furthermore, additional work needs to be pursued to adapt the Automotive Stirling Engines (ASE) for generator applications.

   d. Kinematic (Advanced R&D)
   High-risk R&D could lead to the availability of large frame sizes before 2000; however, extensive R&D efforts would need to begin post haste.

3. Designated Fuel

a. FPSE (Required R&D)
Ongoing programs should be sufficient to ensure operation with diesel fuel.

b. FPSE (Advanced R&D)
Relatively low-risk R&D could be pursued to develop true multifuel capability with engines using a variety of combustible liquids. More high-risk programs could be pursued to achieve operation with solar, nuclear, or solid fuels.

c. Kinematic (Required R&D)
To enable operation with residual fuels, combustion system R&D will be required.

d. Kinematic (Advanced R&D)
Relatively low-risk R&D could be pursued to develop true multifuel capability with engines using a variety of combustible liquids. More high-risk programs could be pursued to achieve operation with solar, nuclear, or solid fuels.

4. Acquisition Cc

a. FPSE and Kinematic (Required R&D)
Ongoing programs are geared toward the values listed in the Task 1 report.

b. FPSE and Kinematic (Advanced R&D)
Value engineering directed at alternate high-temperature materials and coatings could significantly reduce system cost.

5. O&M Costs

a. FPSE and Kinematic (Required R&D)

Field test programs will be required beyond the currently planned activities to develop system reliabilities and maintenance procedures consistent with projected values for O&M.

b. FPSE and Kinematic (Advanced R&D)

None recommended.

6. Efficiency

a. FPSE and Kinematic (Required R&D)

Extensive ceramic component development programs will need to be pursued to enable Stirling engines to achieve the level of efficiency predicted for the 2000 time frame.

b. FPSE and Kinematic (Advanced R&D)

The levels of efficiencies projected in the Task 1 tables can potentially be surpassed with technical breakthroughs in ceramics which enable construction of both static and dynamic components.

7. Lifetime

a. FPSE and Kinematic (Required R&D)

The values listed in the Task 1 tables reflect successful ceramic development, and represent optimistic projection. It is unlikely that either accelerated time frame or high operating life values can be achieved with any amount of advanced R&D.

b. Advanced R&D

Not recommended; the required R&D poses sufficient technical challenge.

8. Volume and Weight

AD-A142 241 USAF MOBILE POWER AND FACILITY ELECTRICITY POWER 2/2
SYSTEMS ANALYSIS VOLUME 2..(U) APPLIED CONCEPTS CORP
WOODSTOCK VA J S HAUGER ET AL. MAR 84
UNCLASSIFIED K08-FR-1-83-VOL-2 AFWAL-TR-84-2015-VOL-2 F/G 10/2 NL

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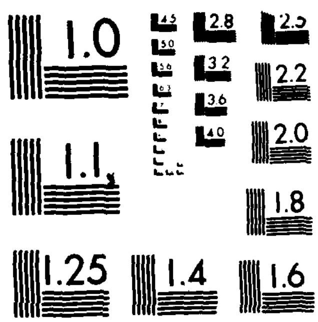

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

a. FPSE and Kinematic (Required R&D)

Ongoing programs will require value-engineering tasks to ensure that projected specific power can be achieved in a timely fashion.

b. Advanced R&D

It is possible that even higher levels of specific power can be achieved through advanced development programs aimed specifically at this objective.

Summary

Based on the above recommendations, the R&D requirements were ranked in terms of the priority of development resources that should be applied to Stirling engine research to achieve the Task 1 parameter values. This result is listed in Table 2. Advanced, high-risk R&D recommendations were also prioritized, and are listed in Table 3. In both cases, the ranking reflects engineering judgements.

TABLE 1

MAJOR STIRLING ENGINE R&D PROGRAMS

Sponsor	Program	Contractor
DOE/NASA	Automotive Stirling Engine	MTI
DOE/JPL	Solar Stirling Engine	Advanco/USAB
MERADCOM	5-kW Kinematic Engine Generator Set	SPS
MERADCOM	3-kW FPSE Generator Set	MTI
GRI	Residential FPSE Development	MTI
GRI	Kinematic Stirling Engine H/P	SPS

TABLE 2

REQUIRED STIRLING ENGINE R&D

Ranking	Deficiency	Recommended R&D
1	Limited life and efficiency due to high-temperature metal constraints	Ceramic-engine development
2	Limited controls availability for operation of kinematic engines as electric power generators	Kinematic engine generator set development
3	Design limitations to smaller frame sizes	Engine upsizing (both FPSE and kinematic)
4	Limited experience resulting in O&M cost uncertainty	Extensive field test/reliability development programs
5	Current equipment relfect high weight and high volume	Value engineering for increased specific power
6	Limited fuel experience	Development of residual fuel operational capacity

TABLE 3

ADVANCED STIRLING ENGINE R&D

Ranking	Deficiency	Recommended R&D
1	Limited energy source capability	Expand multifuel operation with liquid and solar fuels development program
2	Theoretical efficiency limited by Carnot temperatures	Accelerate ceramic activities to achieve even higher efficiency
3	Limited capacity size before 2000	Accelerate upsizing development
4	Unit selling price tied to direct materials cost	Accelerate alternative materials investigation
5	Specific power less than that of some alternative power plants	Value engineering for early improvement in unit size and weight

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2.0 GAS-TURBINE R&D REQUIREMENTS

Objective

This report is to identify the research and development (R&D) requirements necessary to overcome deficiencies in current gas-turbine technologies.

Background

Gas-turbine technology is very mature and well-developed. Market factors, economics, and competition from other energy systems have determined the developmental efforts. Gas turbines achieved a monopoly in aircraft applications because of their superior power-to-weight characteristics, which have been responsible for significant R&D effort in this field. Utility gas turbines also attracted considerable R&D resources because of the unique position they enjoyed in that special application; however, in most terrestrial applications, gas turbines, in their present stage of development, did not compete well and, consequently, sufficient research was not carried out on these systems.

Since gas-turbine systems posess unique characteristics such as lightweight, compact size, quick start, and low maintenance, they may be preferred for certain terrestrial applications by the Air Force. Therefore, in order to overcome the deficiencies, R&D effort, as recommended in the following Sections, is required. Also included are recommendations for high-risk/high-payoff R&D.

Recommendations

1. Modularity

   a. No R&D recommended.

2. Availability

   a. Open-Cycle Units
      No R&D recommended.

b. Open-Cycle Regenerative and Closed Cycle Units

R&D is recommended in compact regenerators to make the units available at competitive prices with good performance in the smaller power ranges.

3. Designated Fuel

a. All Gas-Turbine Cycles (Required R&D)

The use of low-grade fuel oils such as residual oils can create problems. As these problems are not pertinent to aircraft engines, there will be no relevant technology developed by the aero-industry. Fuel heating to improve pumpability, insulation of tanks and washing and cleaning of the fuel have to be investigated to use residual fuels[1]*.

b. All Gas-Turbine Cycles (Advanced R&D)

Diesel fuels offer the conveniences of transportation, mobility, and handling. Advanced R&D is necessary in the area of gas storage in compact form, especially for large-sized power systems.

4. Acquisition Cost

a. All Gas-Turbine Cycles (Required R&D)

Gas-turbine systems manufacture has not reached a plateau in terms of production volumes. The technology, especially as it relates to materials, is constantly changing. Newer and more exotic materials undoubtedly lead to better performance, but result in a constant change of tooling. This situation can only result in cost increases; however, in the 1990-2000 time frame, opportunities for cost reductions are possible with the development of composite materials, ceramics, and computer-integrated manufacturing and engineering systems. As parts are identified in terms of group technology by the CAD/CAM processes[2,3], manufacturing costs will

*superscript numbers represent references at the end.

decrease, especially, modifications will not be expensive. These technologies/systems are currently under development under Government and private funding. Current gas turbine-and large utility systems. Research and development needs in terrestrial energy systems mainly pertain to technology transfer, development, testing, and commercialization.

b. All Gas-Turbine Cycles (Advanced R&D)
Value engineering and computer aided engineering (CAE) are to be developed to bring the system costs down further.

c. Regenerative Open-Cycle and Closed Cycle (Required R&D)
Heat exchangers constitute the main difference between closed and open-cycle machines. R&D into these components will reduce costs. Current efforts are in: 1) helium gas mixtures that posess unique thermodynamic/heat transfer properties leading to minimized total system costs[4] and, 2) component design[5].

d. Regenerative Open-Cycle and Closed Cycle (Advanced R&D)
Value engineering and CAE are to be developed to bring the system costs down further.

5. O&M Costs

a. All Gas-Turbine Cycles (Required R&D)
There are several factors which determine operating and maintenance costs. Planned and preventive maintenance costs would actually go up in the next decade. As a consequence of better management of the O&M operations, the unscheduled repairs and replacement of parts would diminish. There are a number of programs sponsored by the Department of Defense[6], and EPRI programs on High-Reliability Gas Turbines (HRGT)[7]. One industrial program[8] addressed the need for reliable measurements of vital operating parameters such as the turbine inlet temperature. Another program[9] stressed the advantages of generator control cubicle design which provided for easy industrial maintenance

through a complete annunciation, protection, and control of the generator. Continual monitoring of the energy systems is essential to spot imminent failures in time to prevent disasters, and to enable timely corrective action to be taken to keep costs down. R&D is required to transfer technology from the aircraft and utility systems to the terrestrial systems.

b. All Gas-Turbine Cycles (Advanced R&D)

Integrated control offers the user a number of distinct advantages - the ability to make changes and additions through software, and standardization of hardware. The controls should display a sufficient amount of information to aid the operator during normal operation and in troubleshooting any problems that develop[10]. Expert systems and/or specialists remote controllers should be able to monitor the health of the machine, especially to watch for signs of abnormal operation or drift. The design integration of sensors and computer control systems into the original equipment will be more cost-effective. Advanced R&D is required in this area.

6. Efficiency

a. All-Gas Turbine Cycles (Required R&D)

The key to gas-turbine system efficiency increase is the employment of high-turbine inlet temperatures. This, in turn, requires development in materials and cooling systems. The DOE-sponsored High-Temperature Turbine Technology (HTTT) Program has design growth capabilities up to 3000°F turbine inlet temperatures (II). Transpiration cooling of blades provided high cooling effectiveness, maintenance of low-metal temperatures, high blade damping, ability to sustain damage witout affecting critical blade structural integrity, and very high cycle temperature capability[12]. Precision castings of blades, development of coatings, employment of composite materials, and, finally, the introduction of ceramics are a series of developments enhancing the turbine-cycle performance. Integrated cycle, mechanical, and material design is important to the attainment of high efficiency[13],[14]. Closed cycle systems operating at 2200°F turbine inlet temperature and employing ceramic heat exchangers are providing 45% efficiency[15].

EPRI sponsored the Advanced Cooling Full-Scale Engine Demonstration Program which employs water cooling for stage 1 nozzle to attach the problems of hot corrosion and ash deposition at the hottest components[16]. The downstream components experience successively lower gas temperatures and can take advantage of air cooling.

The required R&D relates to technology transfer, and system design and testing in the above-mentioned areas.

b. All Gas-Turbine Cycles (Advanced R&D)

For the small-sized gas-turbine systems, efficiencies are low, and will continue to be low unless advanced R&D is undertaken. For example, the air mass flow required to deliver 10-30 hp in a gas turbine amounts to between 0.2 and 0.7 lb/sec. This low mass flow permits blade heights and blade Reynolds numbers only, which are at least one order of magnitude smaller than the usual practice[17]. Radial stages may be preferred, but they stress the tip clearance effects. Conventionally, minimum clearances are limited by manufacturing tolerances and bearing clearances, which limits the stage isentropic efficiencies. Advanced R&D is essential for the efficiency improvements desired in the smaller units. Modern manufacturing processes in place balance, precision bearings, and high-speed electrical generators are the areas for such advanced R&D.

7. Lifetime

a. All Gas-Turbine Cycles (Required R&D)

Until a few years ago industrial gas turbines used the same alloys in the turbine as older jet engines, but under less severe running conditions; however, the industrial units are rated for long life, and burned poor-quality fuel which required different materials and testing[18]. In a number of systems, critical components have only a small life, e.g., 10,000 hours for the automotive 550 bhp GT 601[19], and the overall system life is extended by replacing these components at the time of overhauls; however, there are programs such as the CCGT where, for the nuclear gas-turbine plant, the power-conversion components are designed for the full life of the plant (280,000 hr).

The values projected in the tables provided under Task 1 presume success based on the current R&D expenditures on cooling and materials (especially ceramics) programs.

b. All Gas-Turbine Cycles (Advanced R&D Programs)
Long life, low acquisition costs, low maintenance costs a high efficiency are very difficult to obtain at the same time. High efficiencies are achieved by sacrificing life or by opting to replace components as described before. Advanced R&D is required to develop systems which employ high-strength materials that preferentially withstand the various types of deterioration and provide long life. The research effort will be in material processing, manufacturing, cooling design, and continuous monitoring.

8. Volume and Weight

a. All Gas-Turbine Cycles (Required R&D)
With the development and deployment of structural composites, and appropriate designs and higher operating speeds, volume and weights will decrease.

b. All Gas-Turbine Cycles (Advanced R&D)
Research programs in operations research (OR) techniques employing optimization methods to the reduction of volume and weight are needed to achieve values better than those listed in the tables.

9. Raw Materials

a. All Gas-Turbine Cycles (Required R&D)

In the intermediate future, the dependence on strategic materials will increase as more chromium, nickel, and titanium are used. As high-temperature ceramic and composite material technologies develop and mature, the need for strategic materials will decrease[20].

b. All Gas-Turbine Cycles (Advanced R&D)

In order to accelerate the substitution of strategic materials by indigenous materials, R&D and technology transfer work is needed in the devleopment of ceramic and composite materials. Material quality control and assurance systems are to be developed. These areas require advanced research.

10. Reliability

a. All Gas-Turbine Cycles (Required R&D)

In the case of the utility gas-turbine systems, the Edison Electric Institute, Equipment Availability Task Force of the Prime Movers Committee developed and organized a data collection program for reporting and summarizing major electric-power generating unit equipment failures in the preceeding ten years[21]. Their reports assist in the design, operation, and maintenance of equipment.

It is essential to have similar programs in the terrestrial energy systems so that components with poor operating reliability can be targeted for development.

b. All Gas-Turbine Cycles (Advanced R&D)

With the advent of computer information/storage systems and laser marking systems, components can be tagged and cummulative livers can be recorded and monitored. Such advanced research programs will enable the improvement of processes, materials, components, and operating parameters to increase the reliability of systems.

11. Environmental Constraints

a. All Gas-Turbine Cycles (Required R&D)

Oxides of nitrogen and sulfur (NO_x and SO_x) are critical environmental emissions that have to be reduced to minimum levels in gas-turbine power systems. Future systems that employ high combustion temperatures will have more restrictions placed on their use unless these problems are solved. In certain systems, the compressor design is shown to be the key to low emissions[22]. Water or steam injection into the combustor is being investigated under several programs[23,24,25]. Where synthetic fuel gases are burned, the NO_x emissions are found to be most sensitive to the concentration of NH_3 and hydrocarbon fuel in the fuel gas[26]. Lean combustion with stratified charge fuel injection appears to be particularly attractive[27]. Combustion chamber design and water injection to control emissions are important research areas. Noise reduction is possible through nacelle acoustic lining technology[28].

b. All Gas-Turbine Cycles (Advanced R&D)

Since water injection has many benefits relative to emissions, cycle efficiency, and material use, integrated R&D into these comprehensive issues should be conducted. Water quality conditioning and control need also be addressed in such R&D work.

<u>Summary</u>

Based on the above recommendations, the R&D recommendations are ranked in terms of the priority of development resources that should be applied to gas turbines to achieve the Task 1 parameter values, and are shown in Table 1. Advanced high-risk R&D recommendations are prioritized as shown in Table 2. A sampling of current R&D programs is given in Table 3.

TABLE "

REQUIRED GAS-TURBINE R&D

Ranking	Deficiency	Recommended R&D
1	Low efficiency and life due to high-temperature material limitation	Water cooling
2	Low efficiency and life due to high-temperature material limitation	Ceramic components
3	Limited Life	Preventive diagnostics monitoring and retirement for cause
4	Poor efficiencies in small sizes	Manufacturing science improvements
5	Emissions	Water injection, combustor design
6	High acquisition cost	Computer-integrated manufacturing technology
7	High O&M Costs	Continuous diagnostics

TABLE 2

ADVANCED GAS-TURBINE R&D

Ranking	Deficiency	Recommended R&D
1	Material limitations	Composites, ceramic materials
2	Life	Materials, cooling and monitoring systems
3	High acquisition costs	Computer-aided engineering (CAE) in design and manufacturing
4	High O&M costs	Computer controls and diagnostic systems
5	Small turbines very inefficient	Manufacturing technology improvements
6	Emissions	Water injection, combustion control

TABLE 3

MAJOR GAS-TURBINE PROGRAMS

Sponsor	Program	Contractor
Air Force	Retirement for Cause	Battle Columbus
Air Force	High-Temperature Gas Turbine	Several
EPRI	High-Reliability Gas Turbine	Westinghouse, United Technologies
NASA	High-Temperature Industrial Gas Turbines	Westinghouse, United Technologies
Air Force	Automated Diagnostic Systems	MTI

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F-2

Giner, Inc.

Report on Phosphoric Acid and Solid Polymer Fuel Cells

PHOSPHORIC ACID (PA) AND SOLID POLYMER ELECTROLYTE (SPE) FUEL CELL R&D REQUIREMENTS

OBJECTIVE

The objective of the Task 2 effort of the Mobile Electric Power Study regarding the PA and SPE fuel cell systems is to identify and recommend the important areas of research and development required to advance these systems to commercial viability.

BACKGROUND

Most of the fuel cell commercial development effort to date has been directed towards stationary applications such as electric utility power generation and gas cogeneration. However, the argument has been presented that the most efficacious use of the fuel cell's high efficiency at part load would be in the mobile sector (1). Tactical mobile applications (2), ground transportation applications (3,4), and rail and shipping applications (5,6) have recently begun to receive attention. The general activities relevant to the advancement of fuel cell technology for mobile applications are presented in Table I.

In this task, recommendations regarding the needed areas of research to facilitate the advancement of fuel cell technology for mobile applications are given. The recommendations presented below are given two perspectives; (1) R&D required to achieve the parametric values reported in Task I of the study, and (2) advanced high risk R&D which could lead to high pay off regarding the technology development. Because of the infant state of development of SPE technology for applications other than space or water electrolysis, we have listed all R&D regarding this system as "long-term." It should also be noted that some advanced R&D will be required in order to realize some of the PA technology parameters presented in the Task I effort.

RECOMMENDATIONS, PA FUEL CELL SYSTEM

1. Efficiency

a. Required R&D

Improved electrocatalytic activity relative to platinum for the oxygen reduction reaction has been demonstrated by Jalan (7,8,9) for various Pt-alloy electrocatalysts. In addition to the increased initial performance, some of the alloy electrocatalysts exhibited increased stability under actual fuel cell operating conditions (10). These initial results are encouraging and further exploration of Pt-alloy electrocatalysts should prove beneficial not only in terms of fuel cell efficiency, but in terms of system cost and life as well.

b. Advanced R&D

Another approach to improve fuel cell efficiency is through alternate support development. In gas phase catalysis, a synergistic effect between certain catalyst-support systems has been observed. Capitalizing on this approach in the area of fuel cell electrocatalysts could lead to significant performance improvements.

2. Cost

a. Required R&D

Demonstration of cost projections under production scale conditions is needed. Additionally, efficient turbocharging equipment is only available for large fuel cell power plants. The development of efficient turbocharging equipment compatible with smaller fuel cell systems to allow air pressurization would increase the fuel cell performance and lower the cost per kilowatt.

b. Advanced R&D

The development of a stable non-noble metal electrocatalyst to replace the expensive platinum electrocatalyst would be a major advance in making fuel cells a reality. Because of the very low probability of success this effort is given a low ranking.

3. Life

a. Required R&D

To date, most fuel cell development has been for continuous operation applications and the life data under various stop-start regimes is limited. The demonstration of fuel cell life under start-up/shut-down and load following regimes is a necessity. The development of low cost corrosion resistant bipolar plates and stable Pt-alloy electrocatalysts would improve the life.

b. Advanced R&D

The development of alternate supports with improved corrosion resistance would improve the life characteristics of fuel cells.

4. Start-up Time

a. Required R&D

The high temperature of operation of the PA fuel cell system lessens the susceptibility of the anode electrocatalyst to poisoning by CO. However, waiting for the system to heat to temperature would incur unacceptably long start-up times for many mobile applications. To shorten start-up times, research towards the development of a CO tolerant anode electrocatalyst is recommended.

b. Advanced R&D

Research of alternate electrolytes such as triflouromethane sulfonic acid (TFMSA) has proved somewhat encouraging. On smooth Pt, the electroreduction of oxygen in TFMSA at 80°C appears to be considerably faster than in H_3PO_4 at 190°C (11) and the CO tolerance of the Pt electrocatalyst in this electrolyte is claimed to be better (12). However, from a systems point of view, TFMSA has some seemingly insurmountable obstacles. The development of homologs of TFMSA or other acids with the beneficial characteristics of TFMSA and more amenable systems characteristics would prove beneficial to mobile fuel cell systems development.

If we extend the scope of the phosphoric acid fuel cells to CO_2 rejecting low temperature (80-250°C) liquid electrolyte fuel cells, we believe that development of a fuel cell containing aqueous potassium carbonate as an electrolyte would lead to very high pay-offs. This approach has a potential of non-noble metal catalyst and alleviates the problems associated with CO poisoning and CO_2 removal. The specific areas to study will be electrode structures developments.

5. Weight and Volume

a. Required R&D

The development of small efficient turbocharging equipment mentioned under the cost section would also greatly reduce the system weight and volume. Additionally, improved reforming catalysts which are not affected by H_2S are required to reduce the ancillary fuel processing weight and volume.

b. Advanced R&D

Integration of the reforming catalyst in the fuel cell stack would eliminate the need for much of the external fuel processing plumbing. Two approaches, come to mind, "in situ" reforming and "in stack" reforming. It has been projected (13) that in stack reforming would reduce the volume and weight of a 20kW phosphoric acid system from 26 ft^3 to 13.5 ft^3 and from 780 lbs. to 550 lbs, respectively. In situ reforming would effect further reductions in weight and volume.

6. Reliability, O&M Costs

a. Required R&D

Information on system reliability and operating and maintenance costs can only be gained from actual operating experience. This requirement is again more critical for the SPE system where only limited experience in applications other than space has been gained.

RECOMMENDATIONS, SPE FUEL CELL SYSTEM

The SPE fuel cell system has received limited development for commercial applications where cost is a major concern. Consequently, information regarding operation and maintenance costs and reliability is non-existence. However, for a 20 kilowatt SPE fuel cell operating on reformed methanol, specific weights and volumes have been estimated (14) as 16.8 lb/kW and 0.60 ft^3/kW, respectively. The projected cost from the same study was $270/kW. Demonstration of these values will require a major reduction in the polymeric membrane expense. Additionally, optimization of the electrode structure to allow better catalyst utilization and hence a reduction in catalyst loading is also necessary.

SUMMARY

Based on the above comments and recommendations, the R&D requirements needed to achieve the Task I parametric values are prioritized in Table II. The advanced-high risk R&D recommendations for the PA system are presented in Table III. We would also point out that a certain amount of advanced R&D success is required for the PA system to meet its projected costs. The SPE fuel cell research requirements are all judged to be long term and are summarized in Table IV.

Table I

Major Pertinent Fuel Cell R&D Programs

Sponsor	Program	Contractor
DOE/LASL	Phosphoric Acid Fuel Cell Power Plants for Transportation Applications	UTC
DOE/LASL	Solid Polymer Electrolyte Fuel Cell Power Plants for Transportation Applications	GE
DOE, EPRI Consolidated Edison	Phosphoric Acid Fuel Cell Systems-Electric Utility Multimegawatt Program	UTC, W/ERC
DOE, GRI	Phosphoric Acid Fuel Cell Systems - On-Site/Integrated Energy Systems Multikilowatt Program	UTC
U.S. Army	Silent, Lightweight Electric Energy Plants (SLEEP)	UTC, ERC
USAF	Phosphoric Acid Fuel Cell Development for Tactical Mobile Applications	W
EPRI 1200 Contract Series	Phosphoric Acid Fuel Cell Research	Giner, Inc. and others
NASA Lewis Research Center	Phosphoric Acid Fuel Cell Research & Development in the Areas of advanced Electrocatalysts, and fuel cell stacks	Giner, Inc. and others

UTC - United Technologies Corporation
GE - General Electric
W - Westinghouse
ERC - Energy Research Corporation

Table II

Required Fuel Cell R&D

Ranking	Characteristic	Recommended R&D
1	System Cost; Weight; Volume	*Development of Efficient turbo-charging equipment sized for fuel cell application
2	Life; System Cost; Efficienty	*Development of low cost corrosion resistant plates
		*Advanced Pt-alloy electrocatalyst development with increased resistance to sintering and improved performance
3	Start-up Time; System Weight, Volume, Cost	*CO tolerant anode electrocatalyst development
4	Reliability; O&M	*Prototype development and testing under actual conditions
5	System Weight, Volume, Cost	*Development of improved reforming catalysts not poisoned by H_2S

Table III

Advanced CO Rejecting Acid Fuel Cell R&D

Ranking	Characteristic	Recommended R&D
1	Efficiency; System Cost	*Alternate support research
2	Life; System Cost	*Alternate support development with improved corrosion resistance
3	System Cost, Volume, Weight	*Integration of reforming catalyst in fuel cell stack, i.e. "in stack/"in situ" reforming
		*Potassium carbonate electrolyte based fuel cells
4	Start-up time; Efficiency	*Alternate acid electrolyte development
5	Cost	*Non-noble metal electrocatalyst development

Table IV

Long Term SPE Fuel Cell Research

Ranking	Characteristic	Recommended R&D
1	Reliability; O&M	*Prototype development and testing under actual conditions
2	Cost	*Low cost polymeric membrane development
		*Reduction in catalyst loading
		*Electrode structure development
3	System Cost; Weight; Volume	*Development of efficient turbocharging equipment sized for fuel cell application
		*Development of improved reforming catalysts

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F-3

Gregory Flynn, Jr.

Report on Diesel Engines

FOREWORD

Unlike the other engines considered in the Advanced Terrestial Energy Study the diesel has long been used as a mobile generator set powerplant prime mover. Many thousands of these engines naturally aspirated (N. A.) and turbocharged have been built are being built by numerous manufacturers in Europe, Japan, and the U. S. To date turbocompound sets have not been put into service but are rapidly coming along (ref. 1, 2).

Most of the engines over 200HP are turbocharged and the diesel range goes from 3KW to 2500KW using relatively high volume production engines both two and four cycle.

Very substantial work is now going on all over the world in insulating engine components to prevent heat loss and to raise cycle temperature for more efficiency. When cycle temperatures are increased turbocompounding becomes even more attractive.

The use of various ceramics to insulate pistons, cylinders, valves, cylinder heads, manifolds, and turbochargers is rapidly becoming reality. Some of these developments will be discussed as the impact on the diesel engine of the near future will be enormous.

CONCLUSIONS:

1. Increased cycle temperatures increase engine efficiency and make the use of turbocompounding very attractive

2. Application of ceramics to engine parts for insulation or direct substitution permits substantial increase in temperature, engine life, while reducing friction and engine cost.

3. All advanced diesel engines now being developed include the use of ceramics in both reciprocating and rotating parts (turbochargers can be all ceramic).

DISCUSSION:

Ceramic technology is increasingly being applied to diesel engines and to turbochargers. Widespread use of ceramic components is seen in the very near future and many field tests are now underway for such things as turbocharger rotors, tappets, piston cylinder and valve coatings, and in more advanced engine studies direct substitution for piston assemblies, cylinders, and exhaust valves. (ref. 1,2,3,4,5,6).

There are many differences of opinion between investigators as to which ceramic to use and how to apply it. The leading contenders being:

1. Partially stabilized Zirconia
2. Silicon Nitride
3. Silicon Carbide

Silicon Carbide is by far the cheapest and has the lowest coefficient of friction, fig.1. Zirconia is basically much more expensive and the Nitrides are costly to process. SiC is made from coal and sand both in abundant supply in the U. S. and is less costly to process than cast iron or steel.

Although ceramics were originally used to permit higher cycle temperatures formerly limited by the metals used the very large reduction in friction was an unexpectedly big bonus in increasing efficiency and reduction in engine weight. These benefits apply as well to the turbochargers, rotor and housings. The very substantial reduction in overall engine friction recently reported by Timoney and Flynn (ref. 3) may have far more overall benefit than the increased cycle temperature originally striven for. Fig. 2. These developments are being continued at an accelerating rate.

Silicon Carbide powder is being applied to Rolls Royce tank engines by Laysrsall Engineering in England. The ceramic is honed into the cast iron cylinder liner and provides a 300% to 600% increase in engine life.

Cummins Engine Company and TACOM, Detroit Arsenal are well along with the "Adiabatic" military engine as are the Japanese who enjoy enormous government financial support for their ceramic programs. No details regarding the Japanese efforts are available but it is known that they do have operating automobiles with major ceramic components. Figs. 3, 4, 5 show the Zirconia insulated Cummins engine parts and fig. 6 indicates the gains that are possible.

The TACOM-Cummins project permits a large reduction in engine parts and weight. Radiator, water pump, hoses, clamps etc. are eliminated. The results of Timoney and Flynn indicate that serious

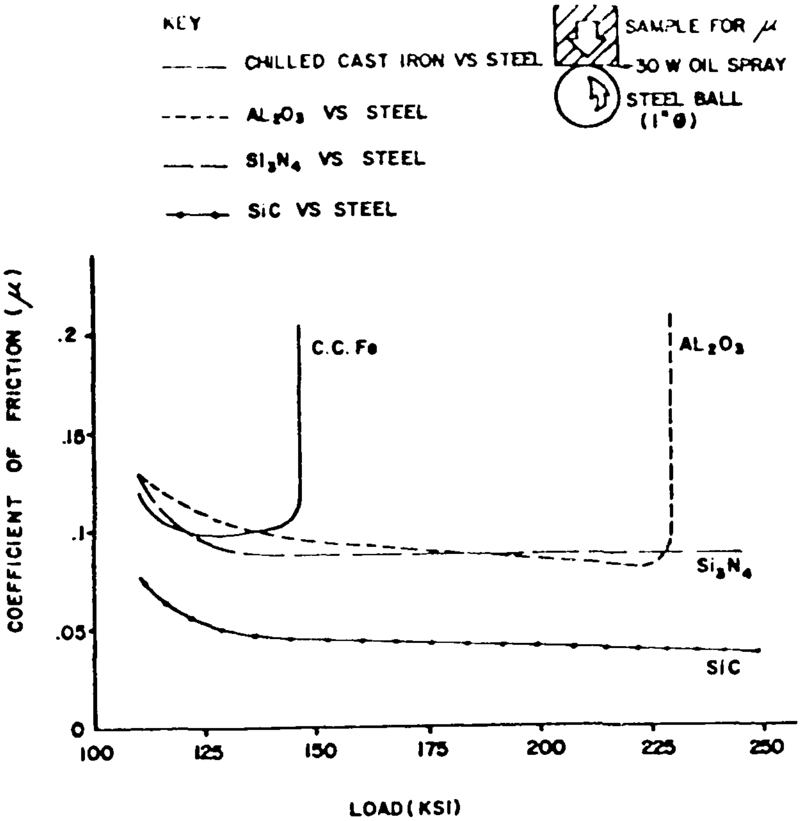


FIGURE 2a: Dynamic coefficient of friction vs. load for several materials running against steel with oil lubrication.

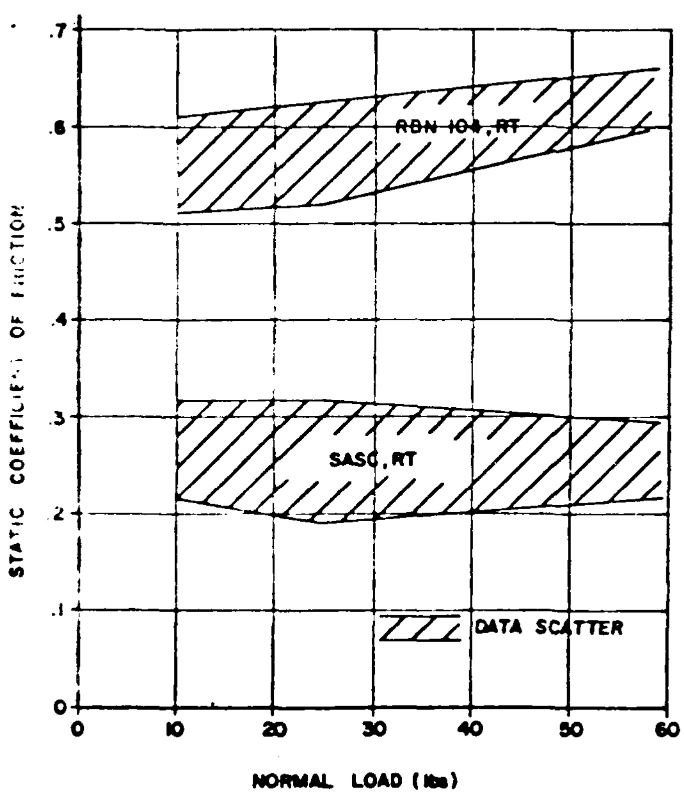
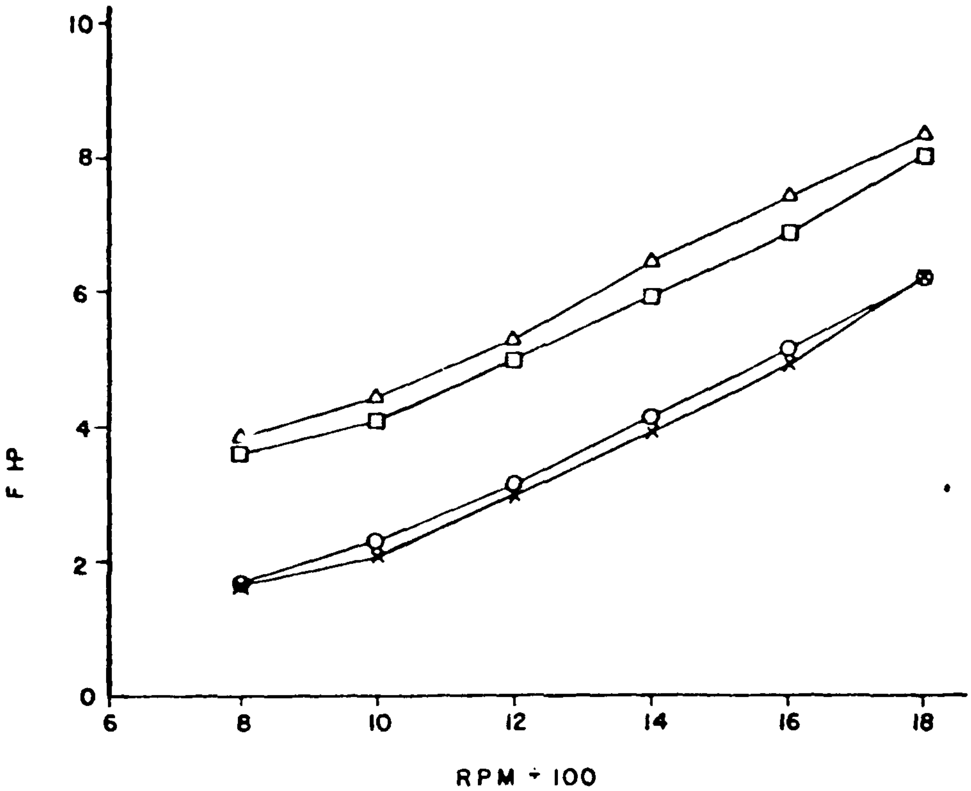


FIGURE 2b: Static coefficient of friction vs. load for unlubricated ceramic samples (running against ceramic).

FIGURE 1

(Timonev & Flynn)
SAE #830313



Δ · LUBRICATED METAL ENGINE

□ · UNLUBRICATED SiC ENGINE, INITIAL FIRING

O · UNLUBRICATED SiC ENGINE, REDUCED PISTON LINER CLEARANCE

X · METAL ENGINE WITH PISTONS DISCONNECTED

FIGURE 2

(Timoney & Flynn)

ADIABATIC DIESEL ENGINE

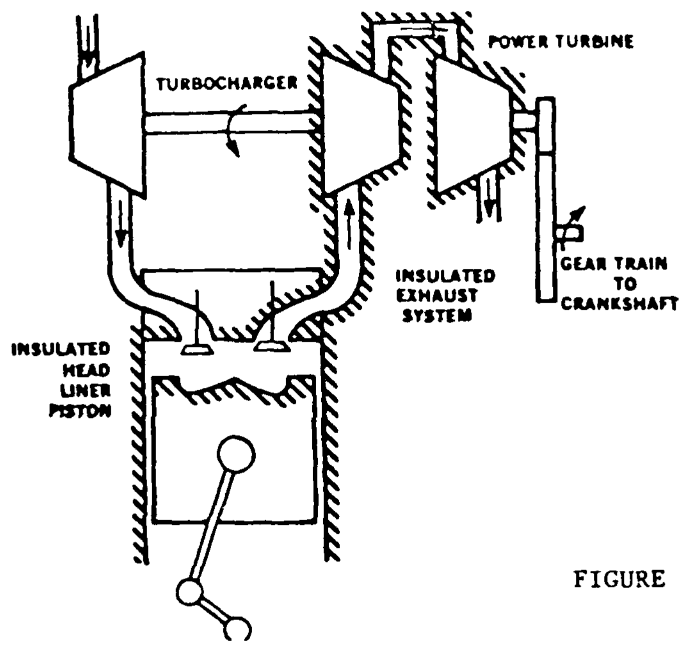


FIGURE 3

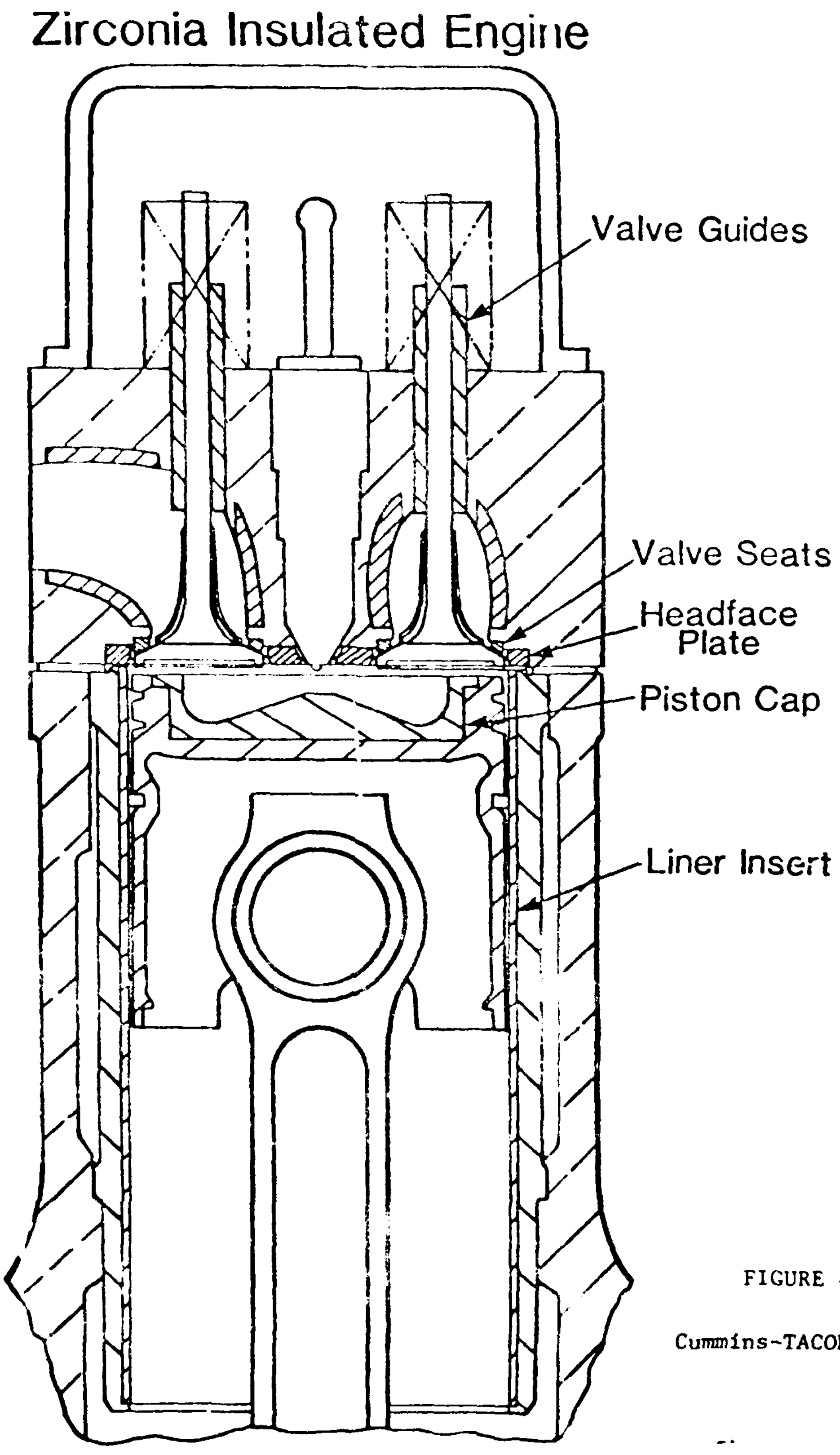


FIGURE 4

Cummins-TACOM ENGINE

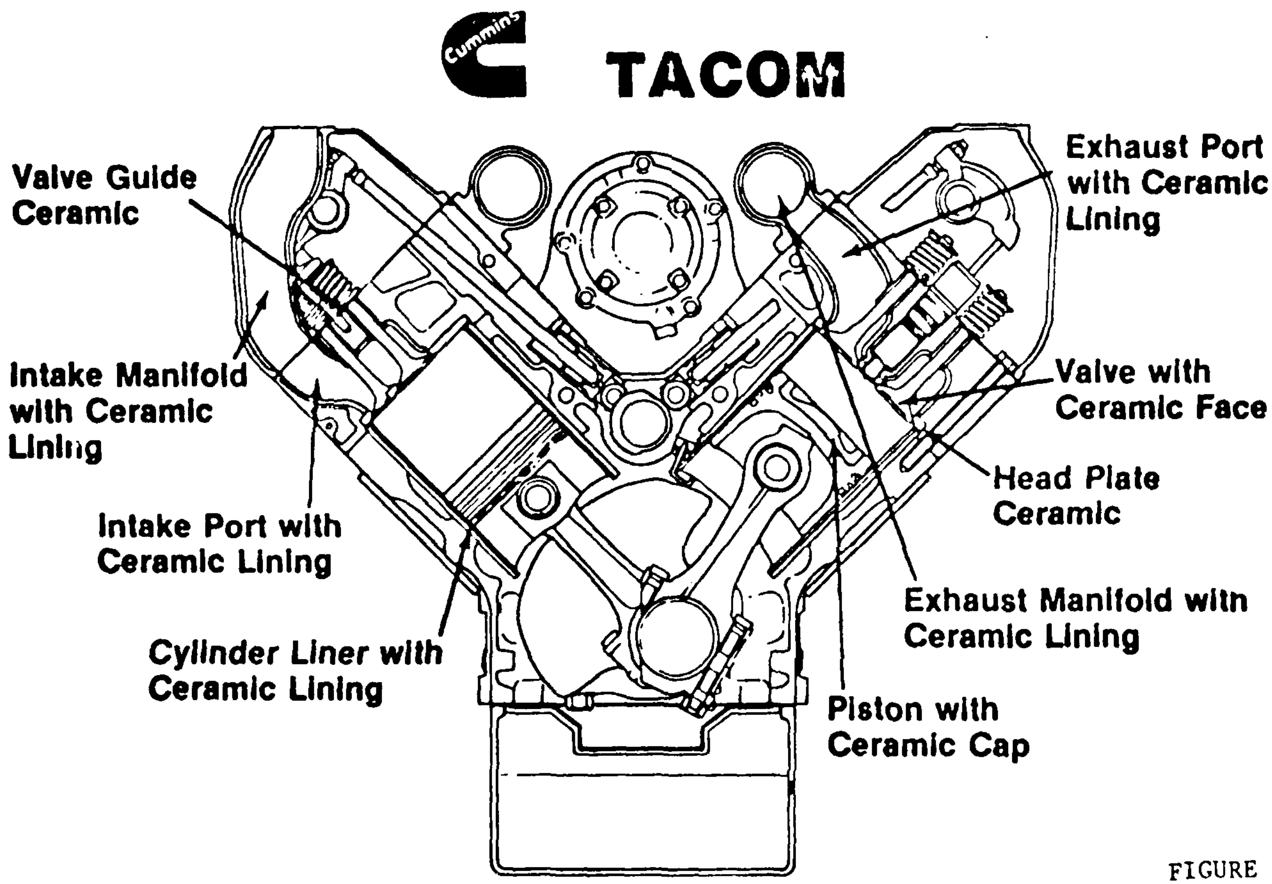

Cummins
TACOM
Valve Guide Ceramic
Intake Manifold with Ceramic Lining
Intake Port with Ceramic Lining
Cylinder Liner with Ceramic Lining
Exhaust Port with Ceramic Lining
Valve with Ceramic Face
Head Plate Ceramic
Exhaust Manifold with Ceramic Lining
Piston with Ceramic Cap

FIGURE 5

consideration be given to the increased use of ceramics. Oil has been eliminated from the reciprocating parts and the logical extension of the Timoney engine is to eliminate it from the crank mechanism by using ceramic rolling contact bearings. This work is now being started by The Carborundum Company of Niagara Falls.

As improvements in cycle efficiency and reduced engine friction are achieved significant reduction in engine size and weight will be possible for the same horsepower or conversely more horsepower for the same package size will be available.

Use of ceramics in the turbochargers will reduce rotating mass, decrease lag time, reduce cost, and permit the elimination of bearings, seals, and lubricating oil. Ceramic components for gas turbines are now under field test and next year Volkswagen will introduce a Silicon Carbide turbocharger which has passed all R&D test work.

The well known Cummins "PT" injection system has been found to have serious deficiences in the TACOM development for "Adiabatic" engines and major improvements will be required. Advanced injection systems such as the "SERVO-JET" accumulator type system of BKM, San Diego will be required. This system has many cost and size advantages and is almost mandatory when fuels other than #2 diesel are considered. A version of the system literally "stolen from BKM" was discussed by Komatsu at the FCIM meeting of SAE last September in Milwaukee.

Accumulator injection systems have much more freedom of control than conventional "jerk pump" systems as the injection pressures can be built up over 160° instead of the 10-15° of the conventional systems. They also lend themselves ideally to the use of electronic controls. Hydraulic intensifiers can be used as in the BKM system and modern microprocessor controls permit the introduction of many variables such as:

Engine speed	Altitude (Bar. Press.)
Engine torque	Temperature
Engine power	Fuel Viscosity
Torque rise	Fuel heating value
	etc.

Being able to inject and burn a wide range of fuels is not always possible with conventional systems such as the Cummins. Simple accumulator systems can handle liquid fuels from gasoline to Bunker 'C' with ease. With some modification they can handle slurrys of powdered coal or other solid fuels.

A very comprehensive report on coal burning diesel engines was published by the Department of Commerce (ref. 7). The very successful experience in Germany after a suitable means of injecting the coal is documented. The largest single remaining problem was that the coal and ash would combine with the lubricating oil and stick the piston rings in the grooves. This road-block to the burning of coal can easily be eliminated by the new ceramic technology which eliminates the piston rings and lubricating oil, Ref. 3.

As the injection of abrasive materials such as coal is considered ceramic injection system parts are attractive candidates for research and some preliminary work has been initiated. All production injectors use very hard Nitralloy steels, hand lapped to selective fits. These parts are susceptable to abrasion by dirt in the fuel a problem that can be eliminated by the harder materials such as the ceramics.

At the present time Cummins, Teledyne, General Motors, and Caterpiller are competing for a major DOD program award for advanced gas turbines and diesels for military vehicles for the 1990s'. All of these engines will have ceramic components by direction of the RFP from DOD. As usual, large spinoffs in commercial engine production will emanate from these military programs.

This discussion brings the reader reasonably up-to-date on the very rapidly moving developments in the diesel engine industry. The specific questions raised by the ATES program are:

1. Modularity

   No R&D required

2. Availability

   N. A. and turbocharged diesel engines are readily available in commercial quantities and commercial prices in the U. S. and elsewhere. No turbo-compound engines are as yet on the market but according to Fig. 7 will be in the very near future. Ceramic turbochargers now running will be in production in 1984-5 in Volkswagen passenger cars.
   Ceramic "Adiabatic" engine components available 1985-1986
   Ceramic reciprocating parts R & D required 2-5 years.

3. Designated Fuels

   Current production diesels burn No. 1 & 2 diesel fuel
   No R & D required.

   Some larger diesels can and do burn heavier fuels up to Bunker 'C'.

   General Motors, Cummins, Caterpiller, Waukesha all make production engines with conversion kits to burn LPG or natural gas, no R & D required.

   Alcohols are now being run experimentally by SouthWest

Research Institute on General Motors and General Electric diesels with encouraging results. Additional development work required.

Solid fuels (powered coal)--R & D required.

4. Acquisition Cost

Commercial pricing readily available and depend on sophistication of control system required for the installation. No R & D required.

Turbocompound diesel will cost approximately 10% more but only reasonable further development is required.

Ceramic components are being aggressively pursued and should result in reduced costs. Much R & D is required particularly the attachment of Ceramic to metal parts.

5. O & M Costs

Operating costs are well known and most manufacturers will quote and guarantee annual maintainence and spare parts costs based on application and use.

Operating costs of turbocompound engines will be slightly higher due to the added mechanical complexity but will be offset by improved efficiency.

Ceramic parts will reduce costs, they have longer life wearing surfaces and are not subject to chemical attack. They will weigh one half that of metals and will reduce engine weight, shipping costs, and fuel consumption. R & D required.

6. Efficiencies

Turbochargeing increases efficiency, no R & D Required.

Turbocompounding increases efficiency, some development required.

Use of ceramics increases efficiency, R & D required.

7. Lifetime

Life of N. A. and Turbocharged diesels is very satisfactory, no R & D required.

Life of turbocompound diesels not yet firmly established, some addition development required.

Life of ceramic parts will be much longer than the metal conterparts due to lower friction and lower weight. R & D required.

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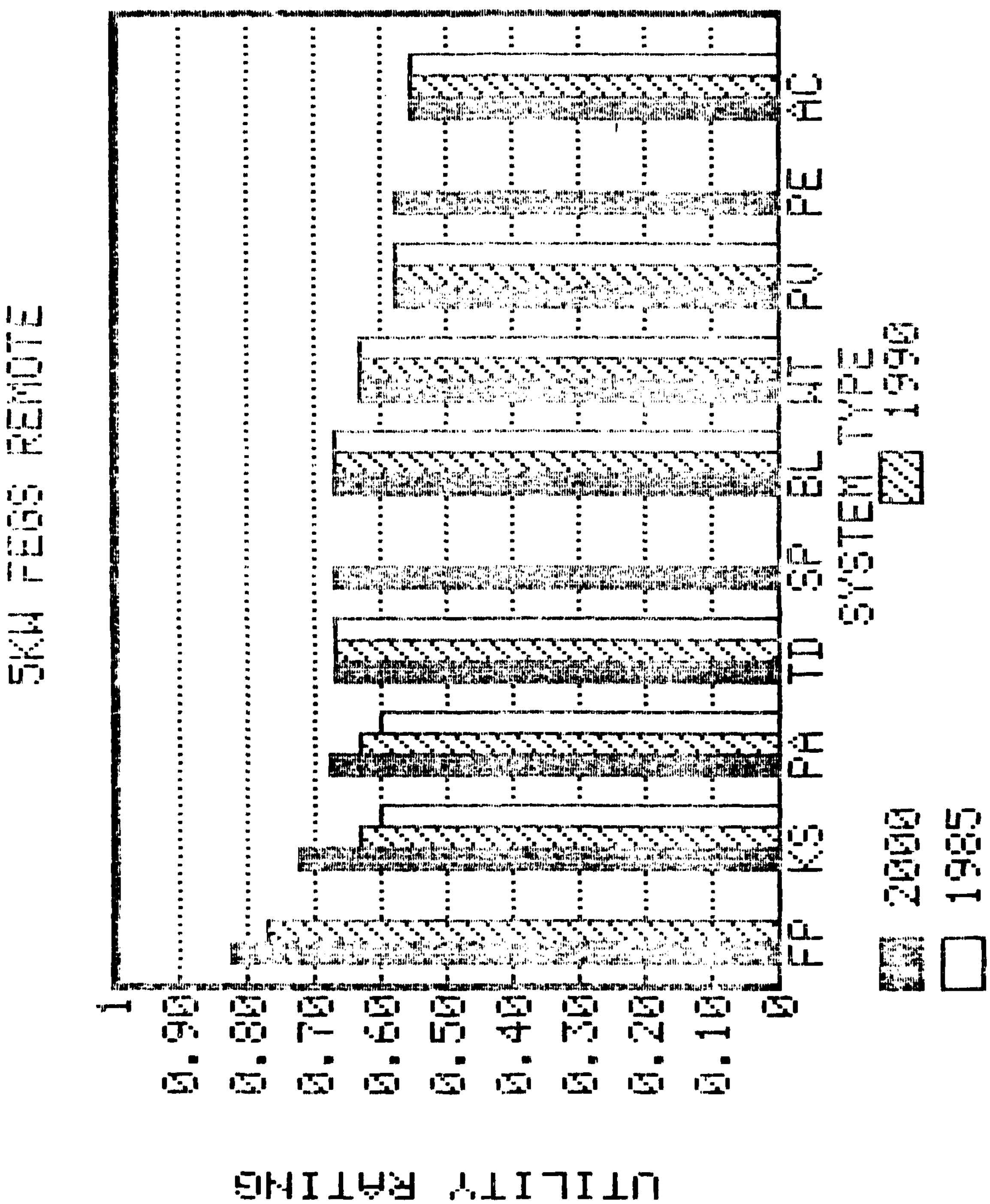
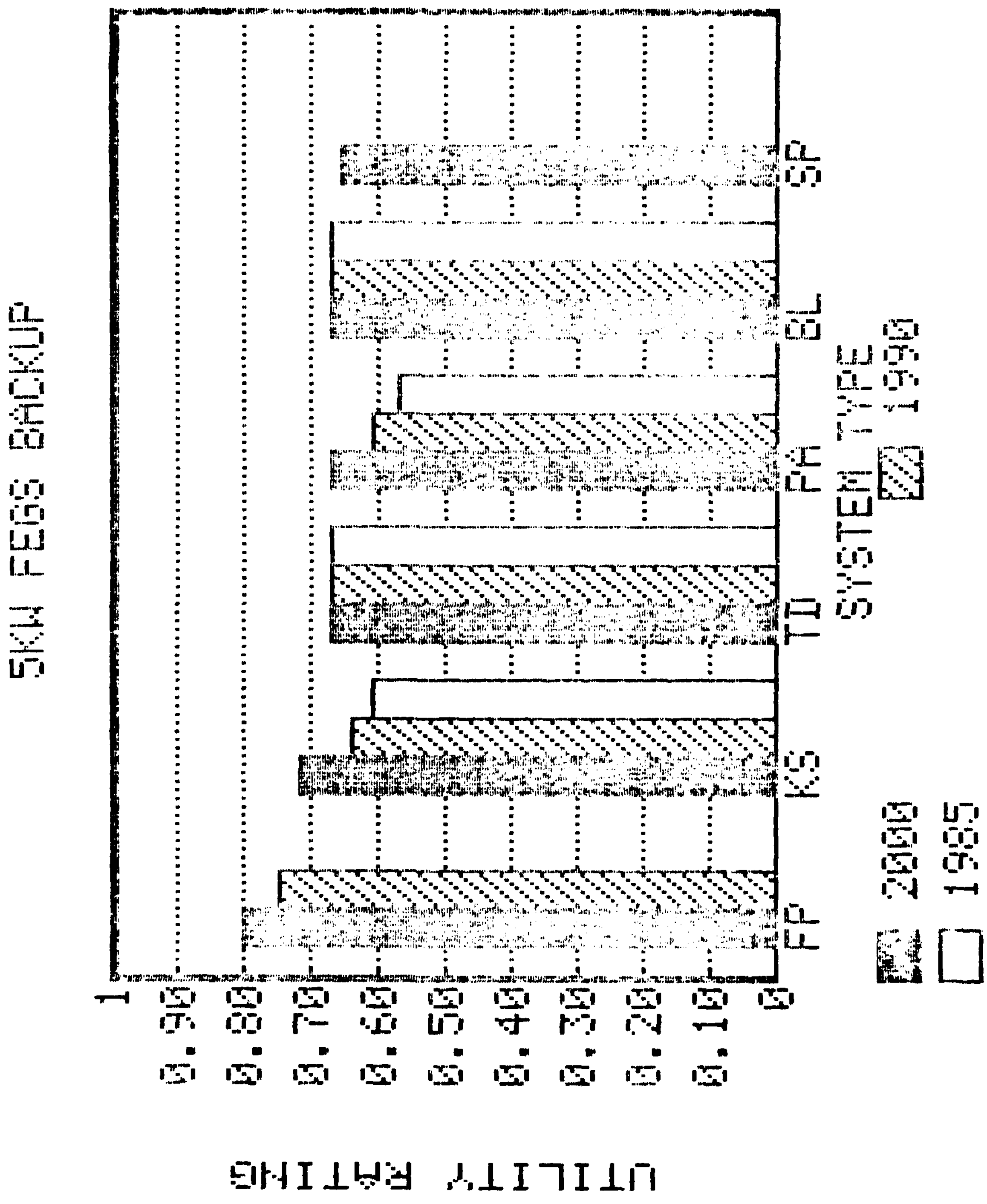
Appendix G

FEGS Utility Ratings


5KW FEGS REMOTE
UTILITY RATING
1
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
FP
KS
PA
TD
SP
BL
WT
PV
PE
HC
SYSTEM TYPE
2000
1985
1990


5KW FEGS BACKUP
UTILITY RATING
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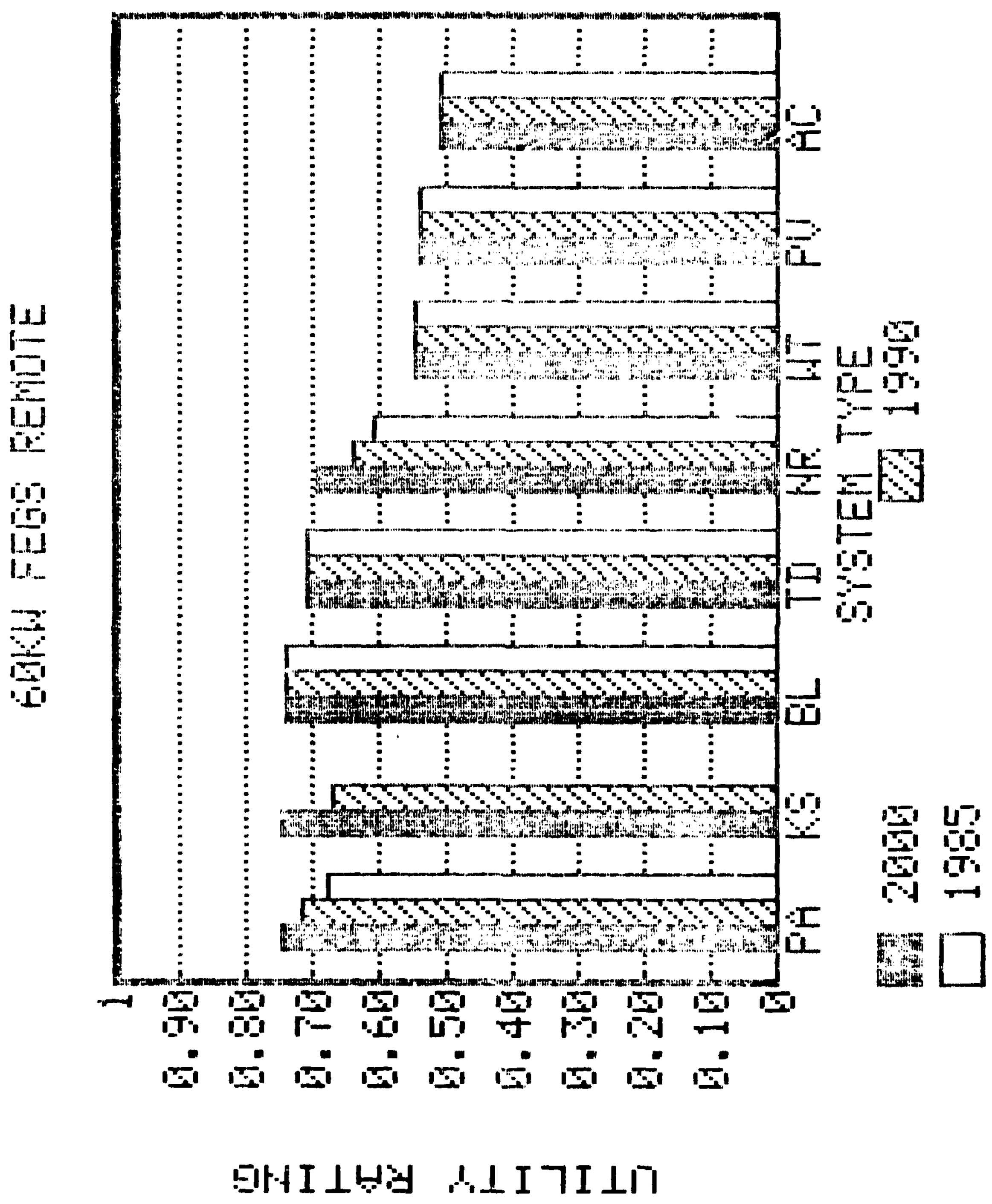
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
FP
KS
TD
PA
BL
SP
SYSTEM TYPE
2000
1985
1990



60KW FEGS REMOTE
UTILITY RATING
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0.80
0.70
0.60
0.50
0.40
0.30
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0.10
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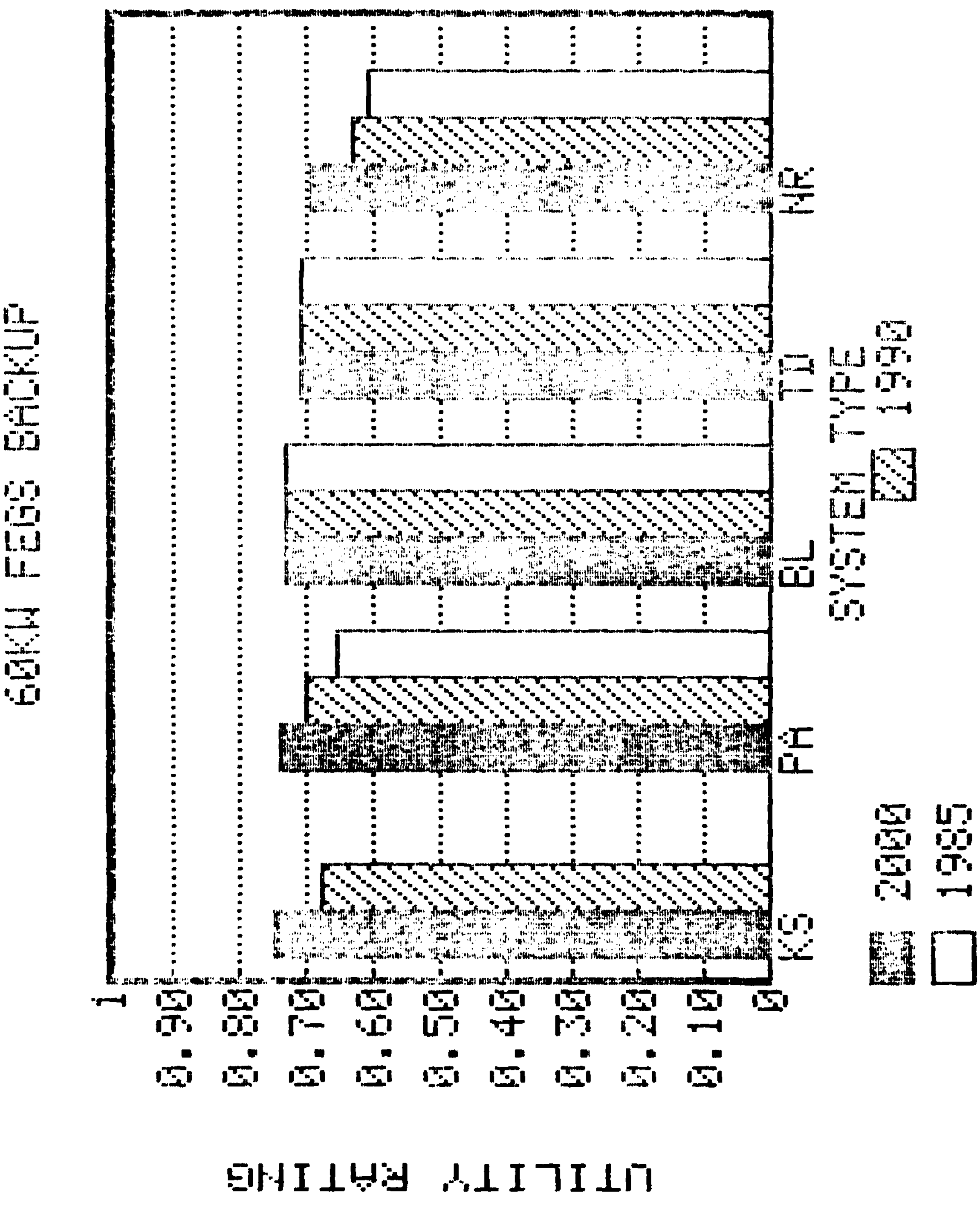
PA
KS
BL
TD
WR
WT
PV
AC
SYSTEM TYPE
2000
1985
1990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UTILITY RATING
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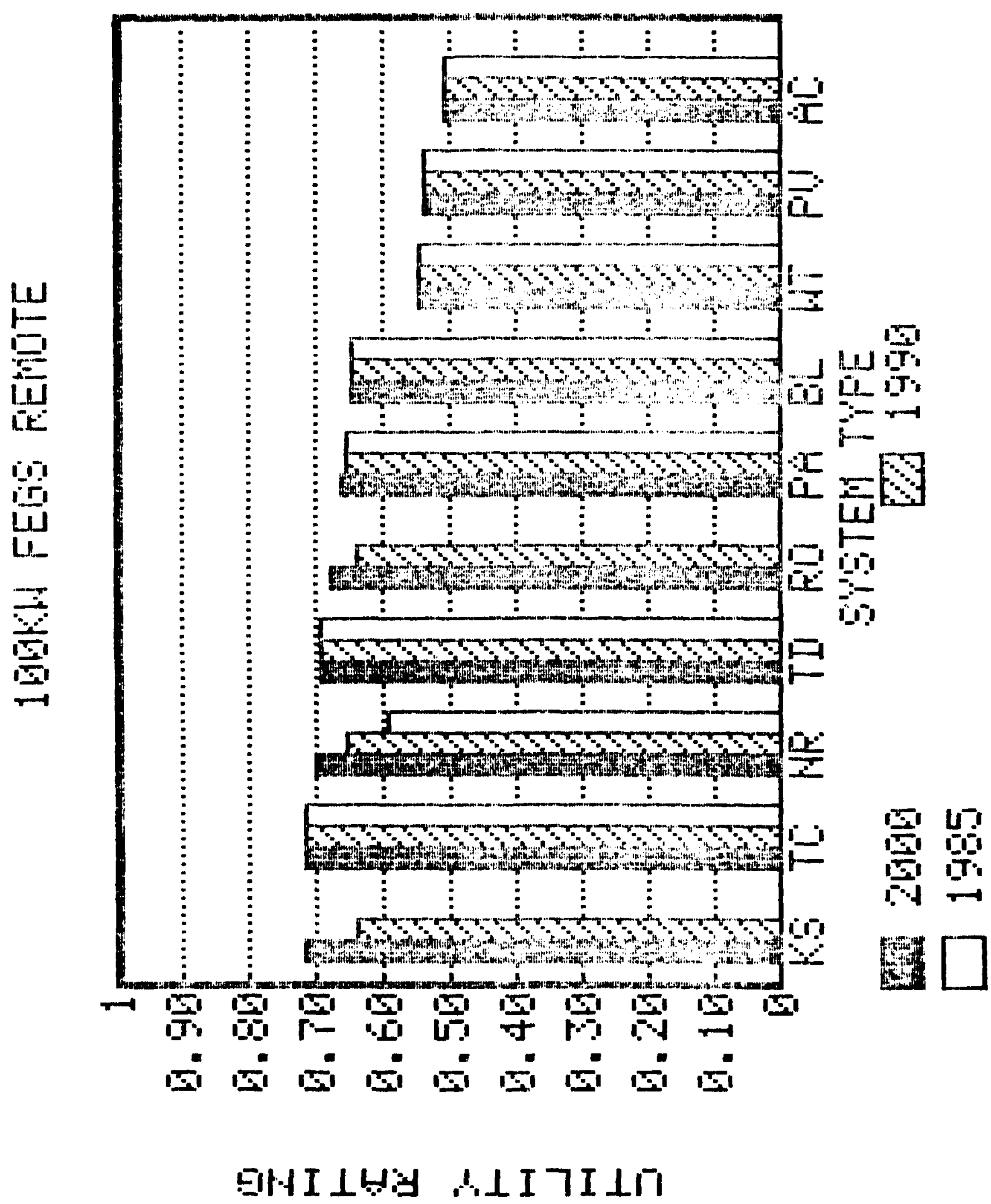
0.10
0
KS
PA
BL
TD
WR
SYSTEM TYPE
2000
1985
1990


100KW FEGS REMOTE
UTILITY RATING
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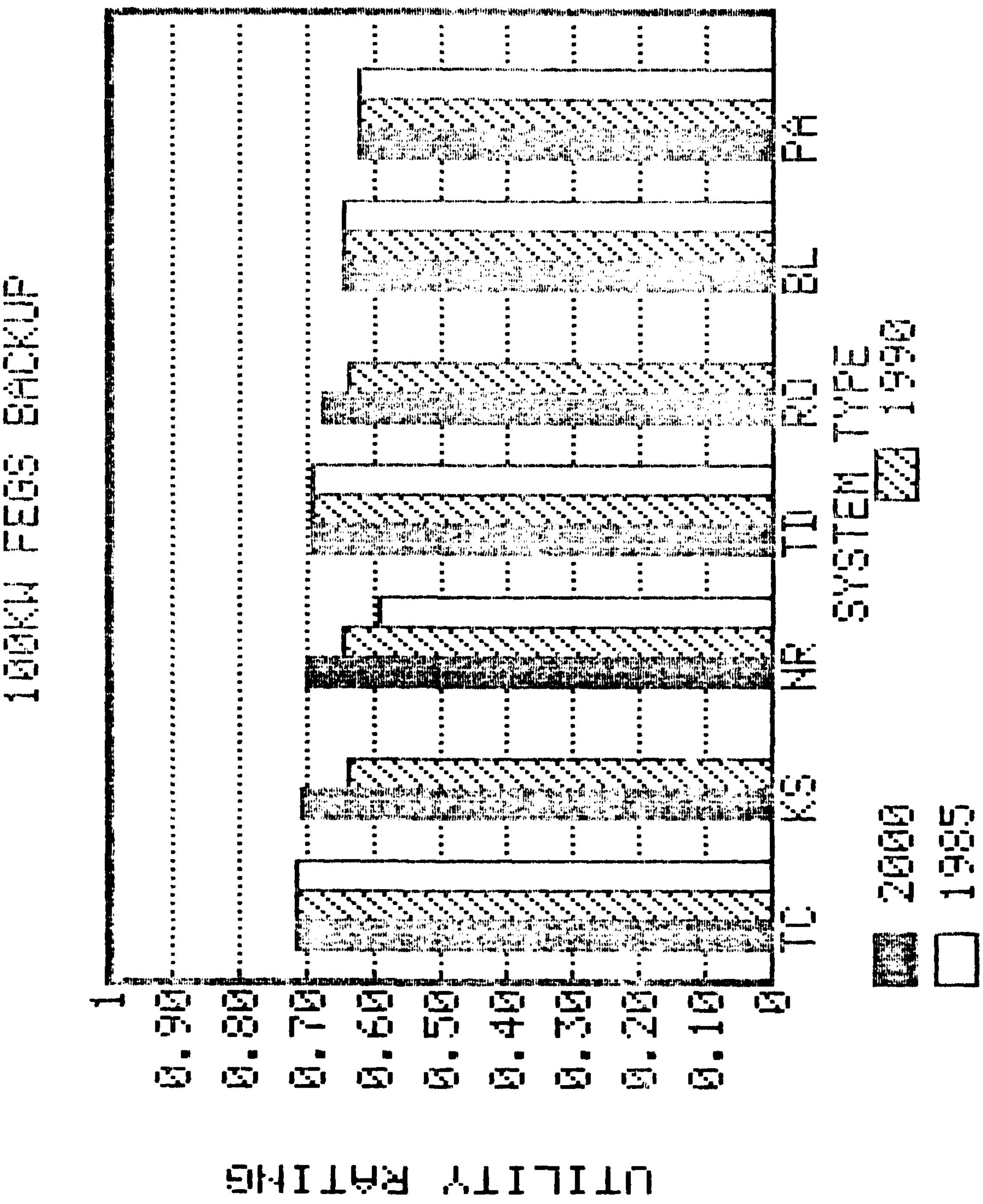
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
KS
TC
NR
TD
RD
PA
BL
WT
PV
AC
SYSTEM TYPE
2000
1985
1990



100KW FEGS BACKUP
UTILITY RATING
1
0.90
0.80
0.70
0.60
0.50
0.40
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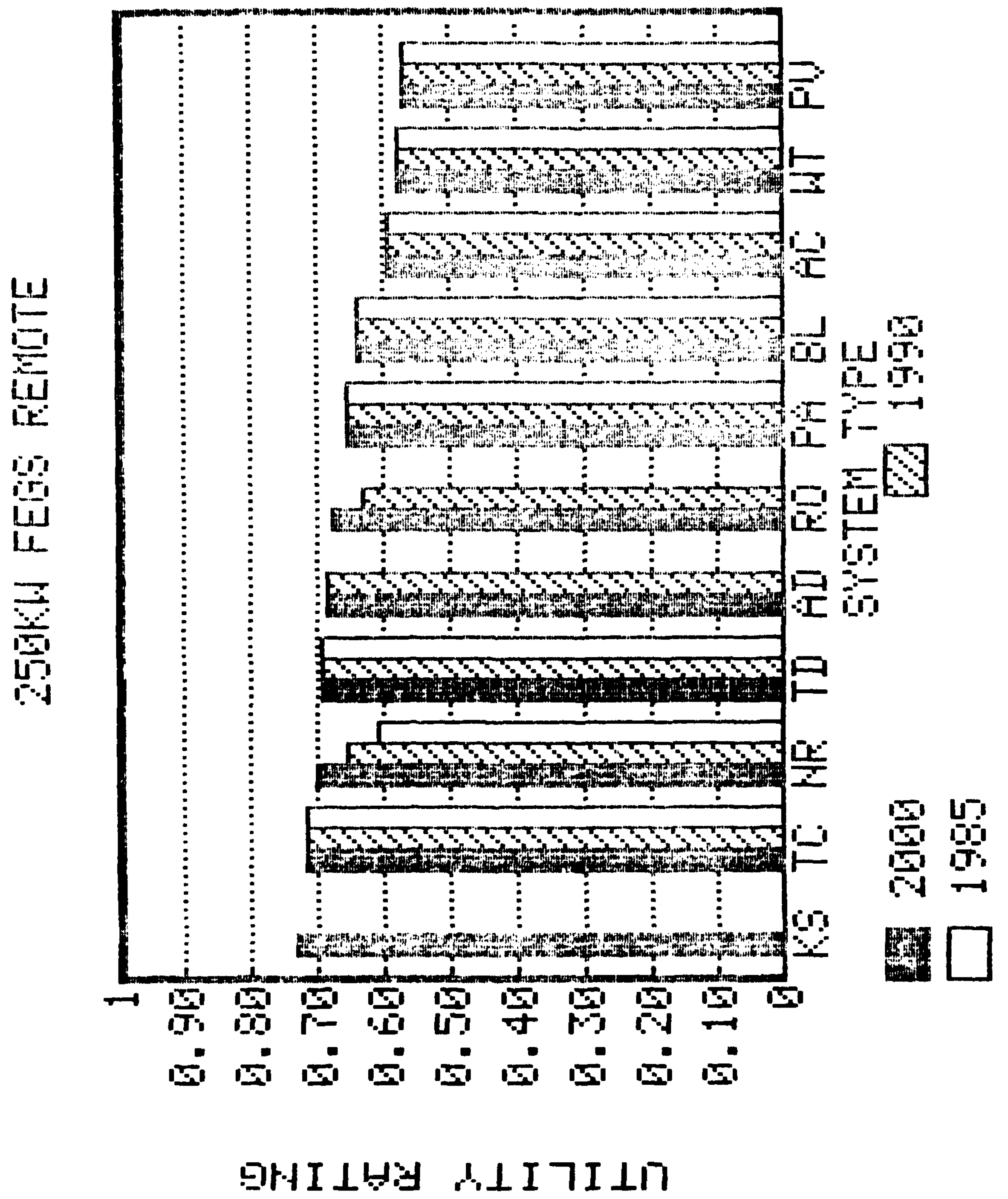
0.20
0.10
0
TC
KS
NR
TD
RD
BL
PA
SYSTEM TYPE
2000
1990
1985


250KW FEGS REMOTE
UTILITY RATING
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0.70
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0.30
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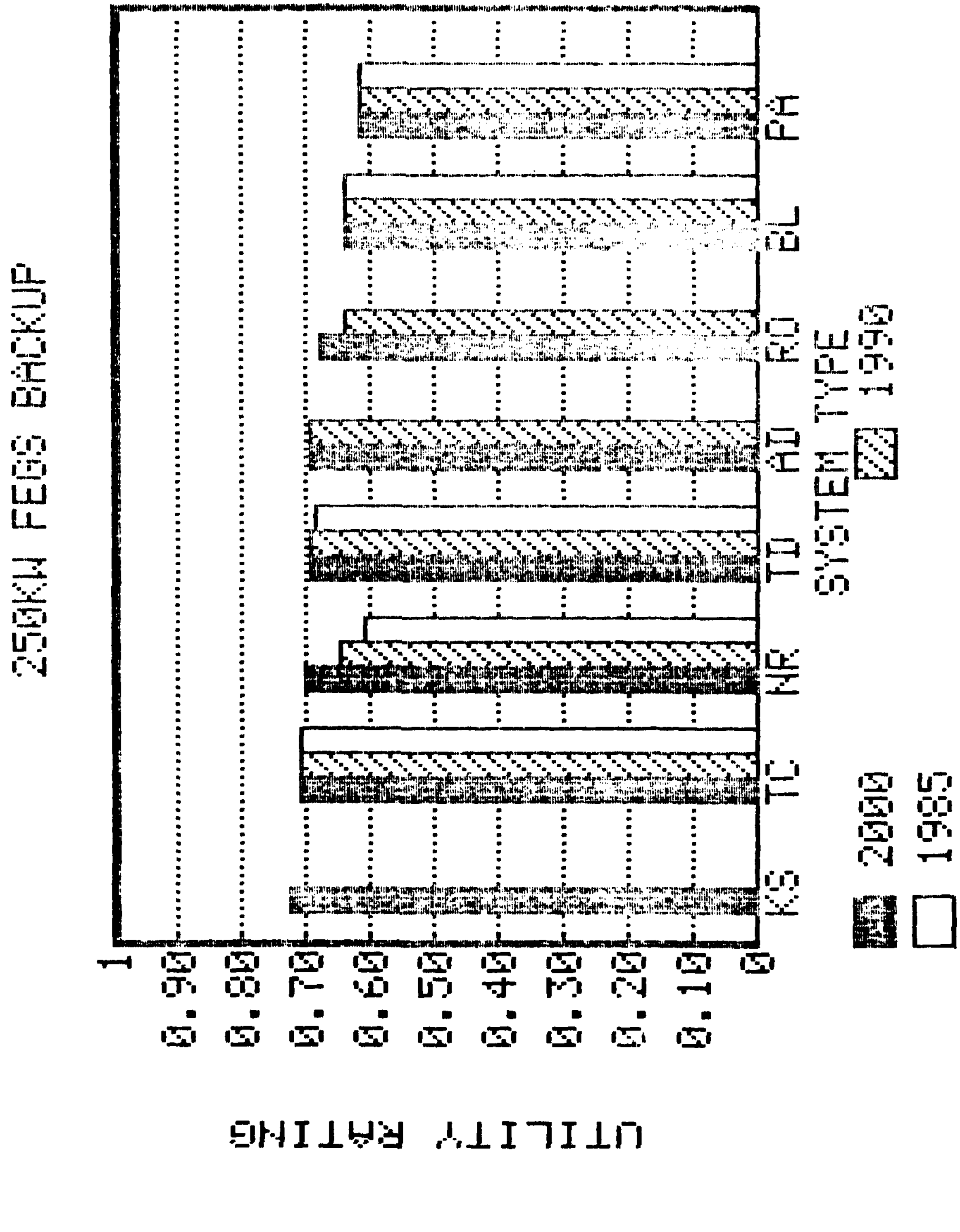
0.10
0
KS TC WR TD AD RO PA BL AC WT PV
SYSTEM TYPE
2000
1985
1990


250KW FEGS BACKUP
UTILITY RATING
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0.50
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0
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TU
AU
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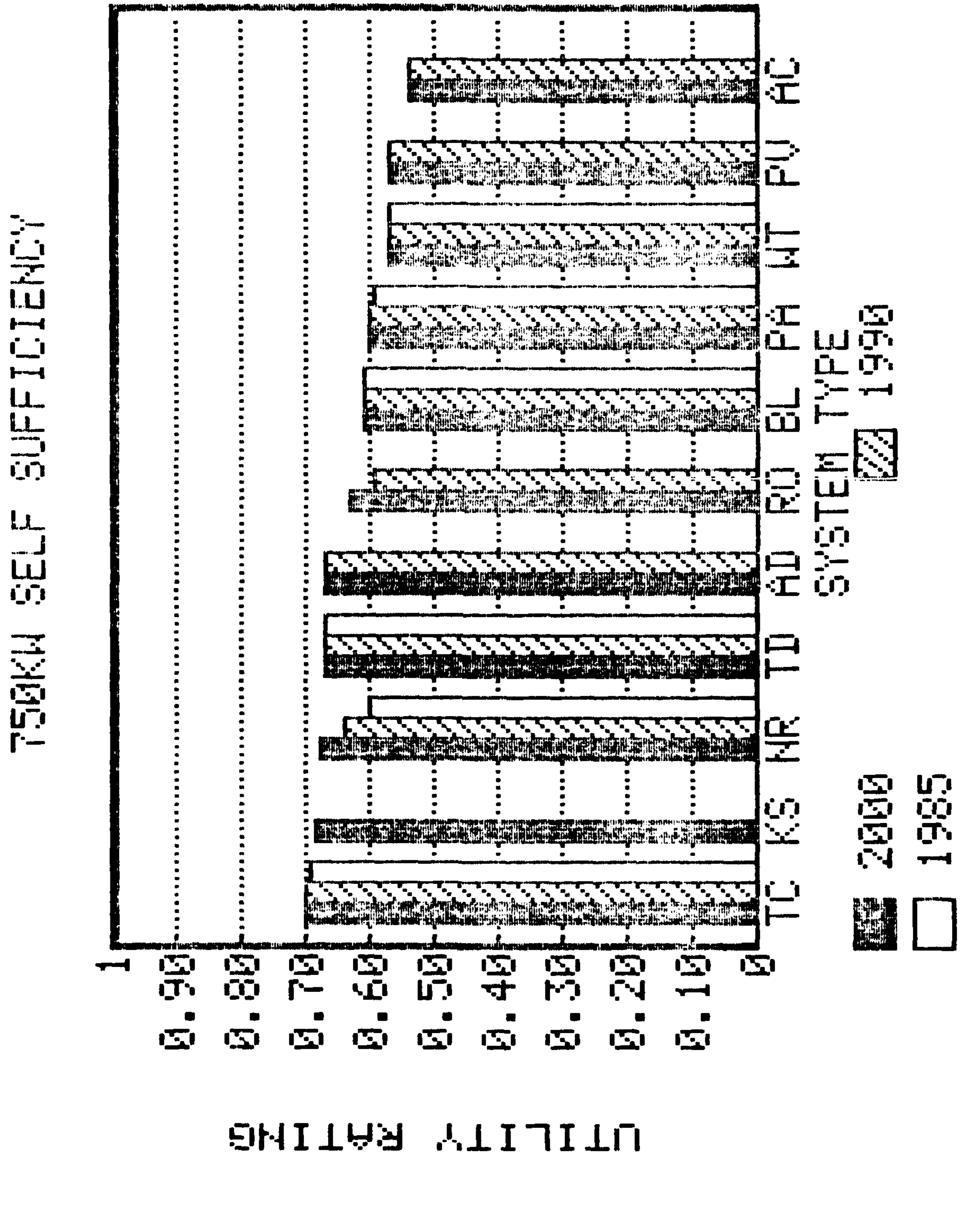
SYSTEM TYPE
2000
1985
1990



750KW SELF SUFFICIENCY
UTILITY RATING
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0.40
0.30
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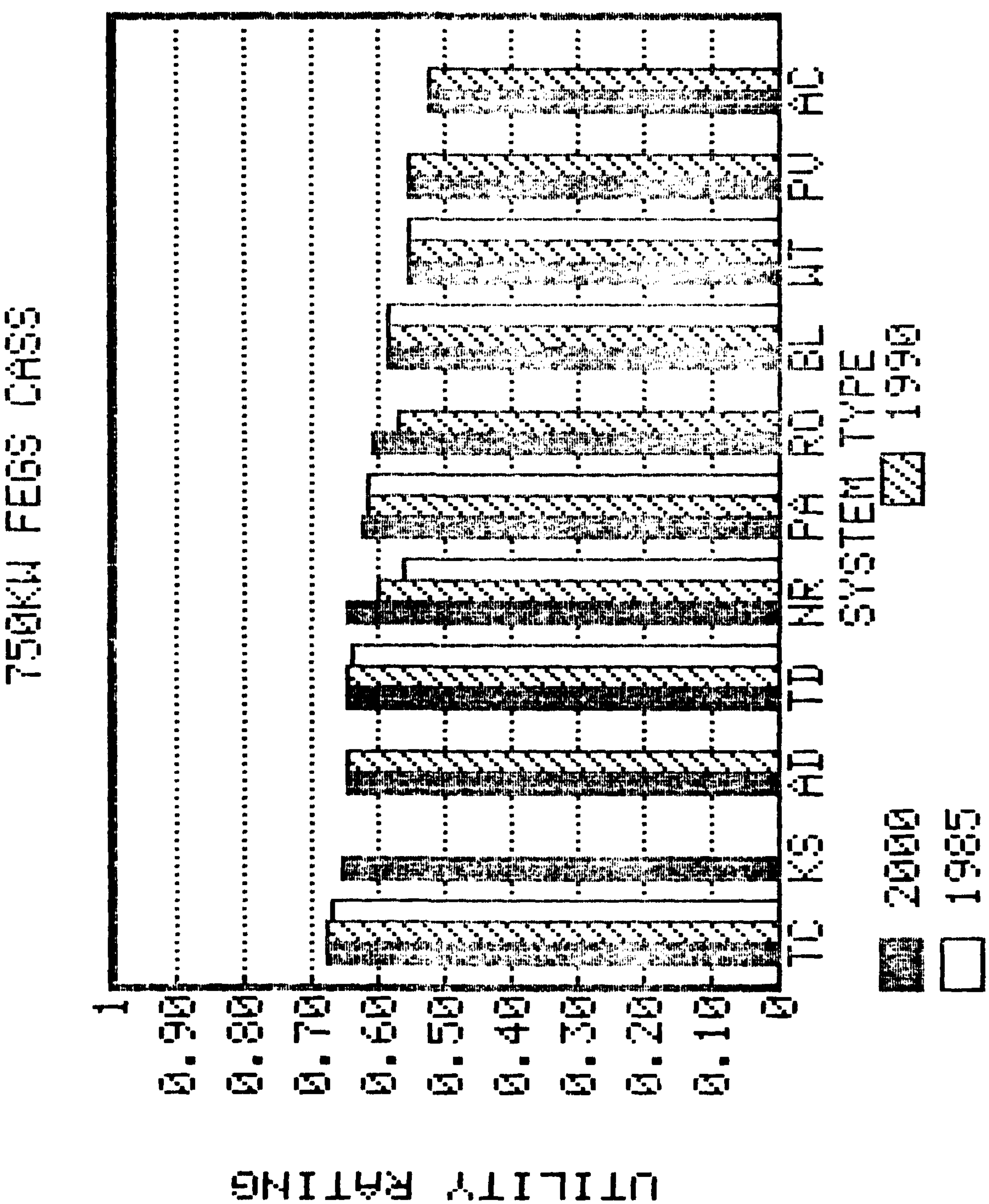
0
TC
KS
MR
TD
AD
RD
BL
PA
WT
PV
AC
SYSTEM TYPE
2000
1985
1990



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UTILITY RATING
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0.40
0.30
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TC
KS
AD
TD
NR
PA
RD
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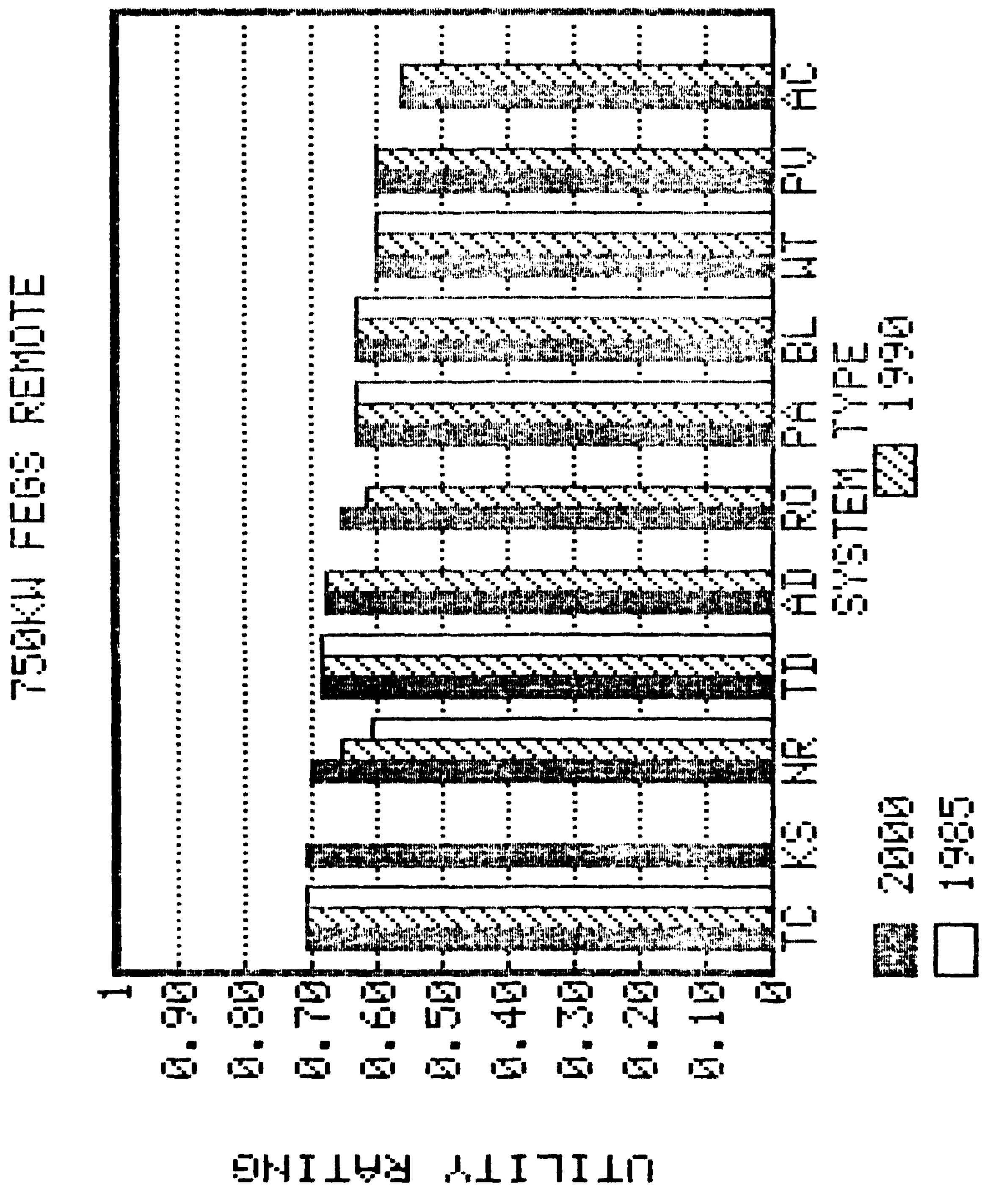
WT
PU
AC
SYSTEM TYPE
2000
1985
1990


750KW FEGS REMOTE
UTILITY RATING
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0.30
0.40
0.50
0.60
0.70
0.80
0.90
1
TC
KS
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SYSTEM TYPE
2000
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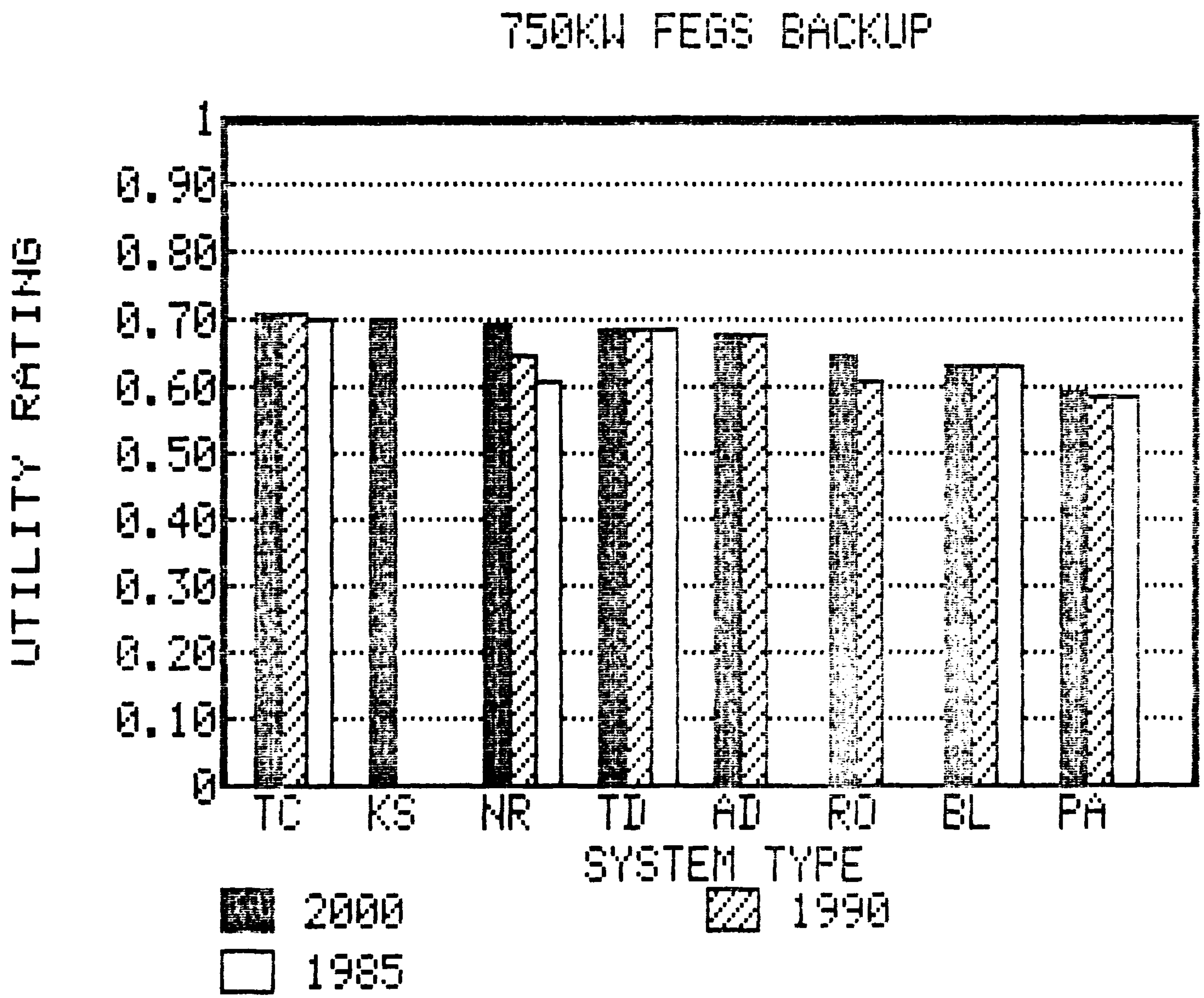
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SYSTEM TYPE
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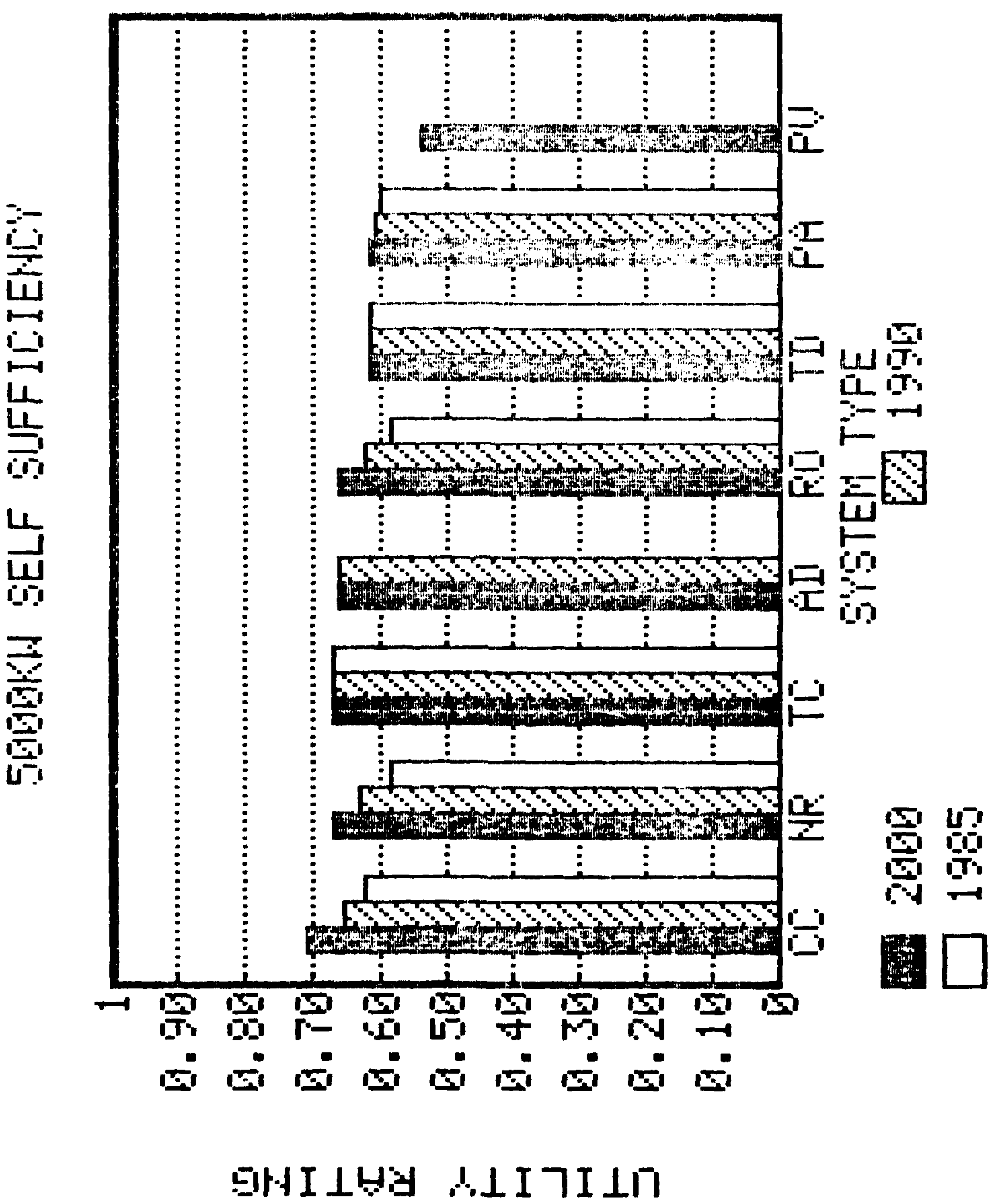

5000KW SELF SUFFICIENCY
UTILITY RATING
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0.40
0.30
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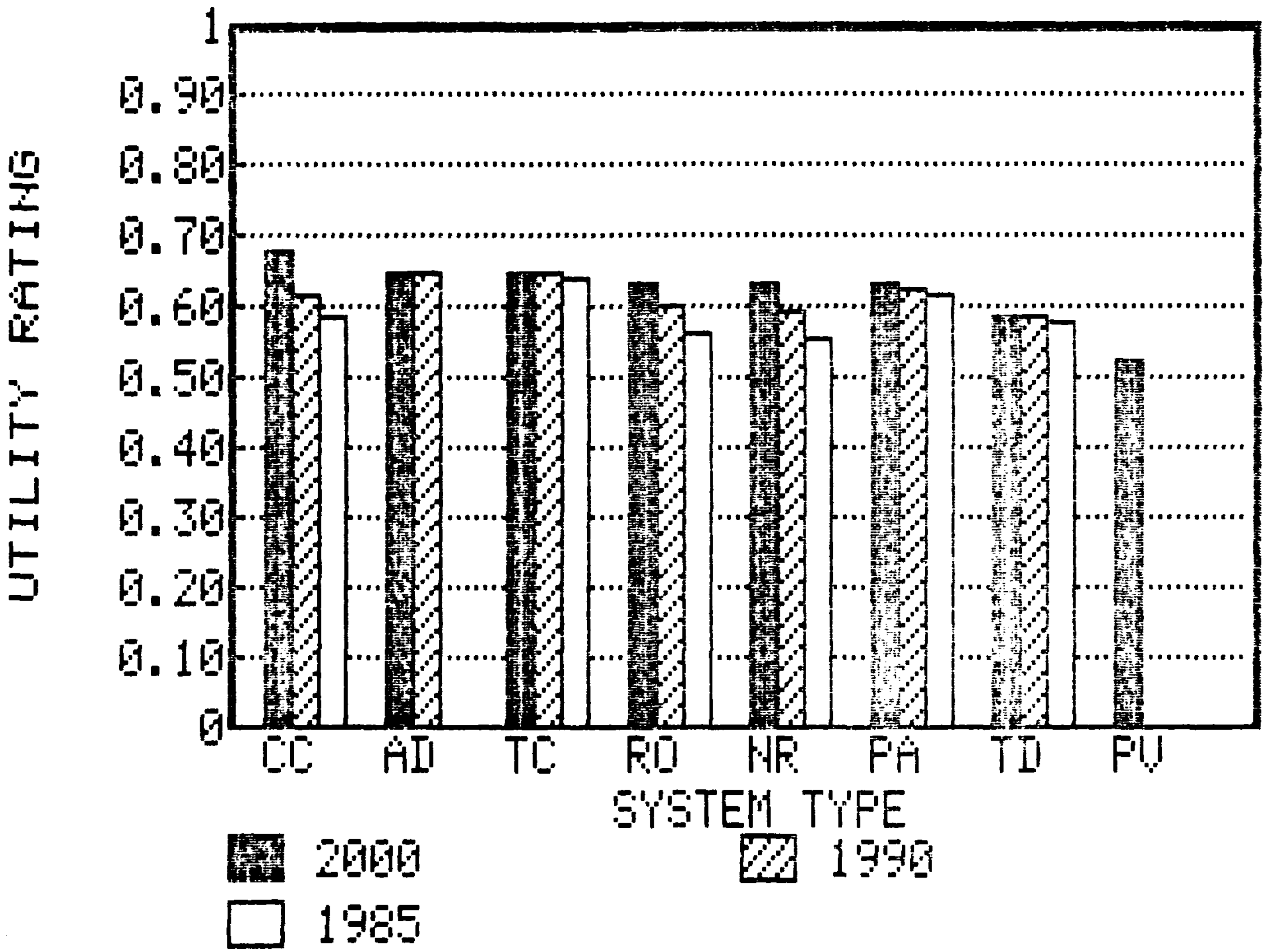
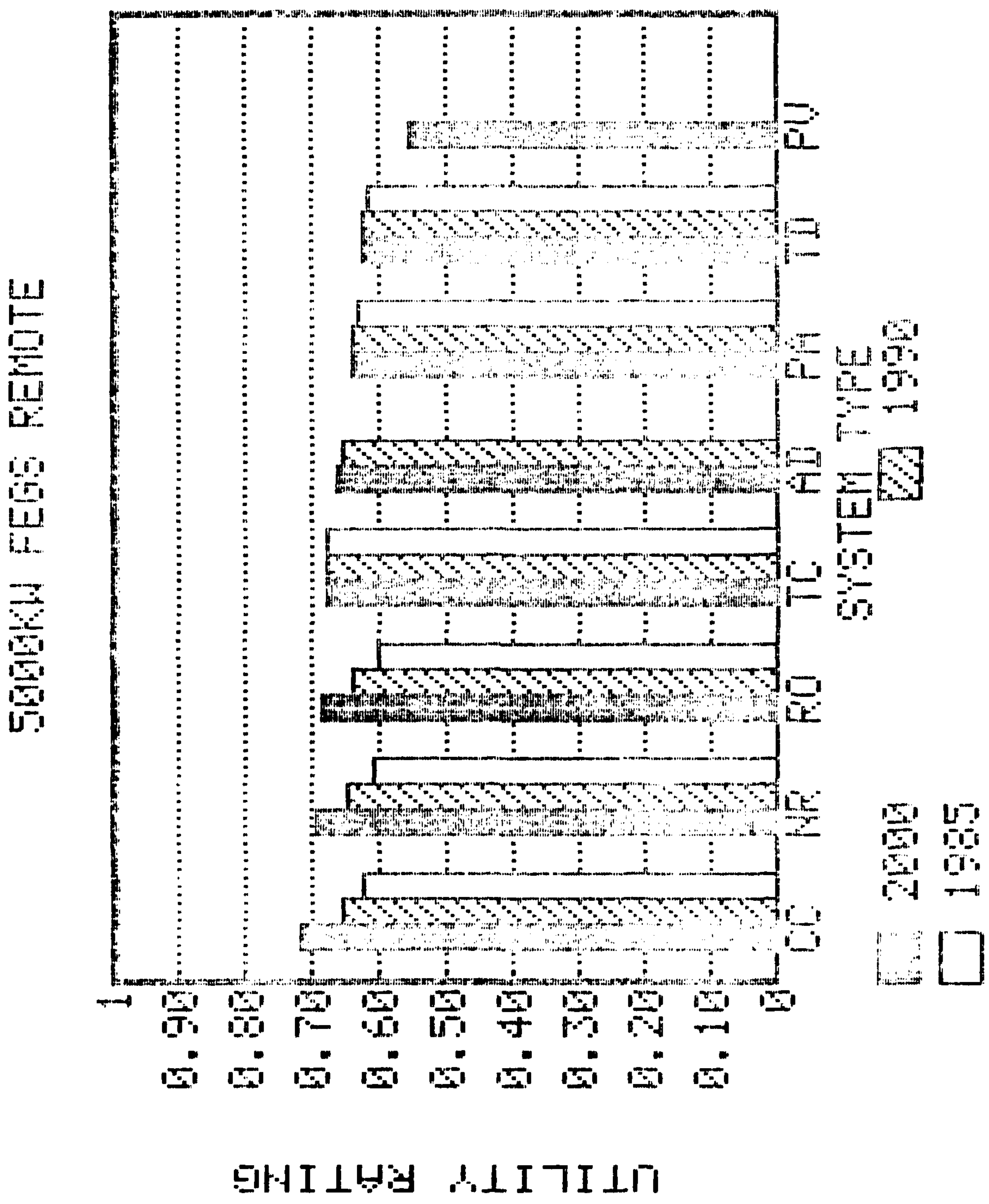
CC
NR
TC
AD
RD
TD
FA
PV
SYSTEM TYPE
2000
1985
1990

5000KW FEGS CASS





5000KW FEGS REMOTE
UTILITY RATINGS
1
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0.80
0.70
0.60
0.50
0.40
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0.10
0
CC
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RO
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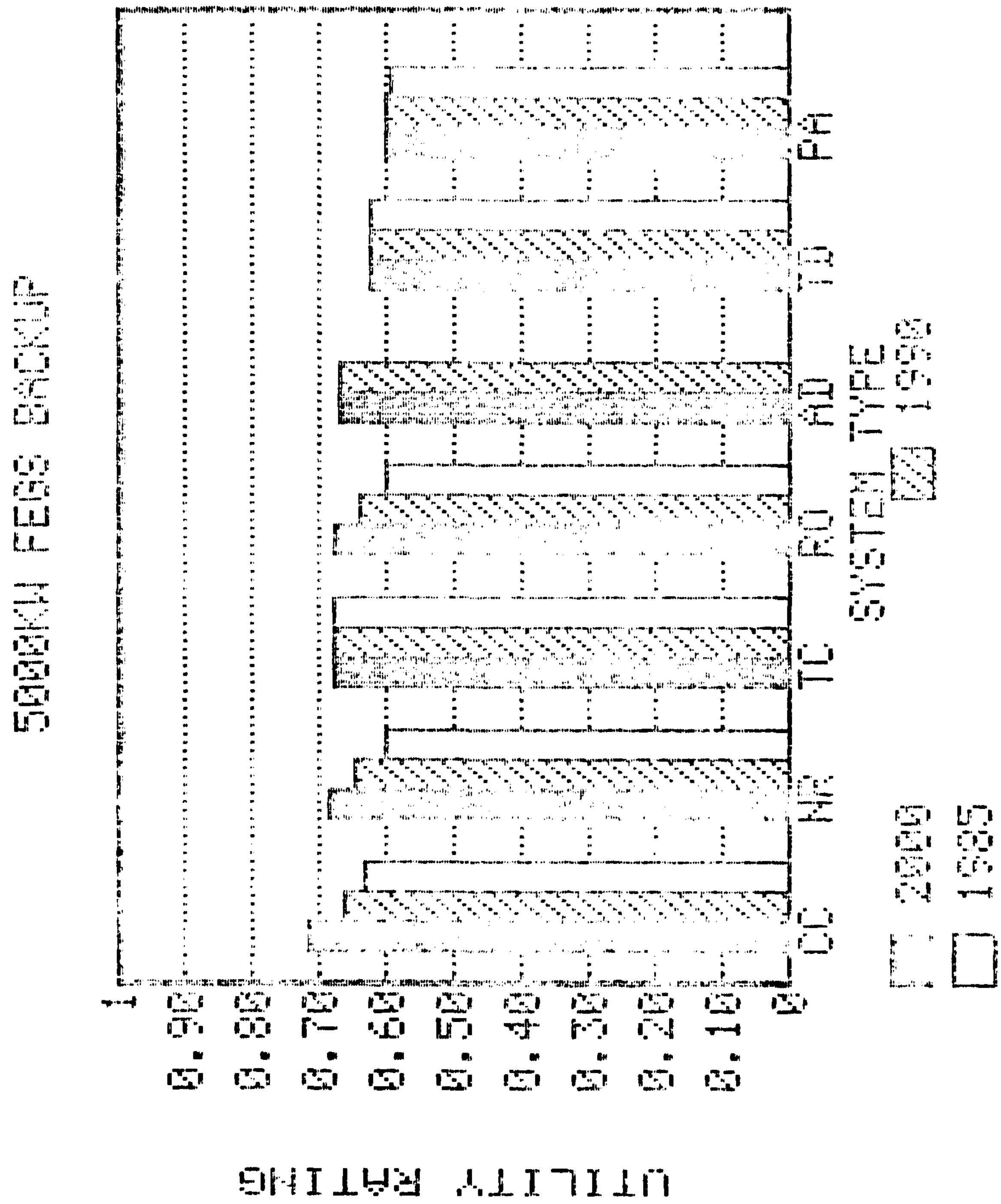

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